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CONCENTRATION OF GOLD IN THE KLONDIKE.

J. B. TYRRELL.

The study of the origin of ore deposits is one of the most fascinating subjects of investigation which the mining engineer or geologist can undertake. The results of his investigations are, in most cases, sufficiently indefinite to escape final conclusions, but at the same time they constantly bring together new groups of facts and ideas which tend towards definiteness and raise hopes of conclusive results.

The uncertainty which hangs over our knowledge of the origin and mode of deposition of ores is especially marked in connection with the consideration of veins or lodes, but the mode of formation of many placer deposits is also not clearly understood, and the source and method of concentration of the gold or other valuable mineral has not been definitely determined.

In the midst of this uncertainty it is interesting to consider briefly the conditions that prevail in the Klondike District, Yukon Territory, Canada, a country of exceedingly rich gold-bearing placers, where the origin and processes of deposition and concentration of the gold into its present position are quite easily recognized and interpreted.

The Klondike gold-bearing District lies in the basin of the Yukon River just south of north latitude 64°, and about fifty miles east of the 141st meridian which forms the boundary line between Canada and Alaska. It is more or less rectangular in

shape, with á greatest diameter in a general east and west direction. Its total area as considered in this paper is about eight hundred square miles.

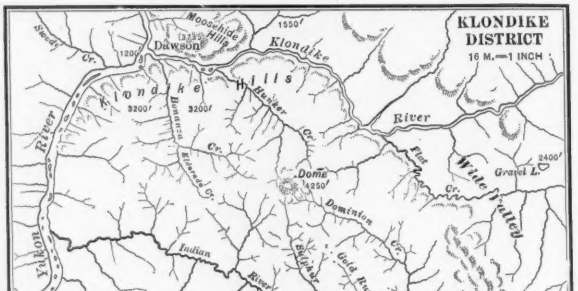


FIG. 34. Map of the Klondike District, Yukon Territory.

It is a well-defined physiographic unit, consisting of a mountain mass separated from all the surrounding mountains of the Territory, except at its extreme southeastern angle, by deep and wide valleys, from which the land rises in easy slopes to a highest point near the centre of the area. The greatest relief is 3,050 feet, this being the difference in height between the bank of the Yukon River at Dawson, with an approximate elevation of 1,200 feet above the sea, and the summit of "The Dome" with an approximate elevation of 4,250 feet above the sea.

The district is bounded on the west by the valley of the Yukon River which is one of the largest streams on this continent; on the north by the equally wide valley of the Klondike River; on the east by a great valley much wider than those just mentioned, that extends along the southwestern base of the Ogilvie Range of the Rocky Mountains and constitutes one of the principal topographic features of the Yukon Territory. On the south the valley of Indian River, a tributary of the Yukon, forms the boundary for the greater part of the distance, the exception being

a narrow ridge at the southeast corner of the area, connecting these mountains with those to the south.

These mountains are not rugged pinnacles and ridges like the Rocky or Coast mountains to the north and south, but their summits are well rounded and their sides descend in gentle slopes into the valleys that radiate in all directions from the highest points. The bottoms of the valleys too, both small and large, have very regular grades, and the streams that flow in them are not interrupted by either lakes or waterfalls. Some of the north-flowing streams have rather steeper and more gorge-like channels cut to depths of two or three hundred feet into and below the bottoms of the old flatter valleys, but even in these the grades are regular and continuous.

The country is largely underlain by schistose rocks which take their distinguishing characters from the presence of sericite, chlorite, graphite or quartz. They are all very old, geologically speaking, dating probably from Precambrian or Cambrian times, and have been very much folded, crumpled and twisted, and consequently they have been greatly altered from the eruptives or sediments as at first formed or deposited.

These schists are cut by many narrow veins, stringers and lenses of gold-bearing quartz, and while these veins, etc., are more numerous and probably more highly mineralized in some places than in others, they would seem to be present everywhere in these schists although in no place have they been found sufficiently closely aggregated, large or rich to pay for mining in themselves. However they are very interesting and important, as the gold collected in the placers in the bottoms of the valleys was derived from them.

In a few places around the margin of the Klondike district outliers of sedimentary rocks of Eocene age occur. During this period the land would seem to have been lowered so that the present four thousand feet contour line was at or near the level of the sea, for at this elevation the remains of a vast peneplain can be traced on the hills, not only of the Klondike district itself, but over great expanses of the Yukon Plateau which stretches

away to the south and west, the rounded tops of the mountains, as seen from any of the higher summits, extending away to the horizon like billows on the ocean. The summit of the Klondike mountain mass evidently formed part of this old peneplain, though some of the largest depressions around and near it were undoubtedly marked out at that time. Assuming that this portion of the peneplain sloped down into the surrounding valleys, which were then submerged, the general elevation of the Klondike mountain mass, taking present sea level as a datum, was about 3,500 feet.

At or shortly after the close of the Eocene period the land was raised above the sea, and it has not since been submerged, so that ever since then it has been continuously subject to decomposition by meteoric agencies, and to subærial and stream erosion, the streams having assumed and retained normal courses outwards from the centre of the mountain-mass.

The district lies in the unglaciated area between the glaciated Ogilvie Range of mountains to the northeast, and the much more severely glaciated Chilcat or Coast Range of mountains to the southwest, and while there is a possibility that during the glacial period it may have had some local glaciers of its own in the higher portions of its valleys, none of the glaciers from the north or south reached it, and there was no transportation of material to it from any outside source. Its problems of erosion, transportation and concentration are therefore entirely confined to itself.

After the land was raised well above the level of the sea atmospheric agencies began the decomposition of the rocks, and the breaking apart and liberation of the rock particles one from another, while the rain and the smaller and larger streams cut out the valleys, dissolved parts of the rock, and washed the undissolved particles from the higher to lower levels. The very heavy particles, such as the grains and nuggets of gold, would settle close to the places from which they were derived, while the lighter particles would be carried farther away.

The processes of decomposition and erosion, with transporta-

tion and separation of the eroded material, went on continuously from year to year and from age to age until the land had been reduced almost to its present level, and the bottoms of the wide and relatively shallow valleys had been filled with coarse pebbles and cobbles of the harder and more resistant kinds of rock, though chiefly vein quartz, that had been slowly washed down from the adjoining hills. Mixed with these larger masses of rock were the smaller but heavier nuggets and grains of gold, which had been washed out of the same hills, but on account of their weight had not been carried away with the rock particles of the same size. The beds of quartzose gravel thus formed are locally known as the " White Gravel " or " White Quartz Wash."

After these gravel beds were formed the northward-flowing streams were accelerated and given greater cutting power in some

FIG. 35. Bank of " White Gravel."

way, probably by a tilting of the land from the south northward, consequent on the continued rising of the mountains near the Pacific Coast. These streams therefore cut narrower valleys, with steeper sides, through the " white gravel " and into the

underlying rock, leaving terraces of the "white gravel" on one or both sides of the valleys, and reconcentrated into their beds the gold from the gravel which they had cut through and washed away, as well as any gold that may have been in the rock cut through below the older gravel.

These two sets of gravel deposits have together produced to date about six million fine ounces of gold, and it is not improbable that there are still four million ounces remaining in the placers, making a probable total gold content for these Klondike placers of ten million fine ounces of gold.

As has been shown above this gold was concentrated by the rills and streams from the whole of the rocky material washed down from the Klondike mountain-mass, and it probably represents a considerable proportion of the gold originally contained or included in the rock.

In reference to the quantity of rock that was so washed down by eroding and transporting agents acting continuously through a long period of time only approximate data are obtainable, but the following statement is believed to represent with a reasonable degree of accuracy the conditions as they existed during the erosion period.

As stated above the mean elevation of the land when active denudation began at the close of the Eocene period was 3,500 feet, taking the present sea level as a datum. The mean elevation of the district at present is about 2,600 feet above the same datum, from which it would appear that the thickness of rock removed from the surface between the end of the Eocene Age and the present time is equal to a thickness of 900 feet over the whole area. Adopting the ordinary time scale of 4,000 years for the removal of one foot of surface, 3,600,000 years would be the time required for the removal of this 900 feet of surface, and such, according to this computation, would be the length of time since the close of the Eocene period. A thickness of 900 feet over an area of 800 square miles would equal a mass of 136 cubic miles or 1,600,000,000,000 tons of rock. This is therefore the quantity of rock that was removed by denudation, and from

which 10,000,000 ounces of gold was washed and concentrated into the Klondike placers, and it represents an average gold content of 0.003 grains or 0.013 cents to the ton of the original rock in place.

It is thus seen that the Klondike district owes it phenomenally rich placers not to the wearing down of highly mineralized gold-bearing veins or lodes, but rather to the favorable conditions of long continued and uninterrupted concentration from a great mass of rock that contained only very minute quantities of gold.

ON THE MICROSTRUCTURE OF NICKELIFEROUS PYRRHOTITES.

WM. CAMPBELL AND C. W. KNIGHT.

INTRODUCTION.

The origin of nickeliferous pyrrhotites is a matter which has been much discussed. By certain investigators they are considered to be due to segregation from a basic igneous magma: by others they are said to owe their origin to secondary enrichment by deposition from aqueous solutions.

As examples we have taken the deposits of Sudbury, Canada; St. Stephen, N. B.; the Gap mine, Penn.; two Norwegian localities and Sohland, Germany. The geological relations and petrography of these deposits have been worked out in detail and will be found in a report by Dr. Barlow on the nickel and copper deposits of Sudbury.[1]

Owing to certain difficulties of examination, the microscopic relations of the opaque constituents have not been clearly worked out. These difficulties disappear when we employ metallographic methods and examine carefully polished and etched surfaces of the various ores by means of reflected light. The method of work has already been set forth in this journal,[2] and we shall, therefore, confine ourselves to the results obtained thereby.

OPAQUE CONSTITUENTS OF THE ORES.

The chief opaque constituents are pyrrhotite, chalcopyrite and pentlandite together with a certain amount of pyrite and magnetite. This research purposes to investigate the determination of the order of their origin. To recognize these constituents under the microscope we are guided by certain characteristics which may be summarized as follows.

[1] Part H, Annual Report, Vol. XIV., Geol. Surv. Canada.
[2] Wm. Campbell, ECONOMIC GEOLOGY, Vol. I., p. 751.

CHARACTERS OF POLISHED SURFACES OF THE CHIEF OPAQUE CONSTITUENTS.

CHALCOPYRITE. Clear yellow color. Takes a good polish. Hardness = 4. Its color is its chief distinguishing characteristic.

MAGNETITE. Steel-gray color. Polishes very well, but more slowly than chalocpyrite. Hardness = 5.5–6.5. It etches differentially along cleavage planes, often yielding a "gridiron" structure.

PENTLANDITE. Light bronze color. Polishes better than pyrrhotite: is not so brittle. H = 4. Sometimes shows a distinct cleavage. Easily distinguished from pyrrhotite by etching.

PYRITE. Pale brass color. Polishes with difficulty. Retains scratches long after the other constituents. H = 6–6.5; therefore it polishes in relief.

PYRRHOTITE. Light bronze color, similar to pentlandite. More brittle than pentlandite and shows a more pitted surface. H = 4. By immersing in hot HCl (1 acid to 1 water) pyrrhotite is attacked, pentlandite is not.

We may therefore easily distinguish chalcopyrite, magnetite and pyrite by color and habit from pentlandite and pyrrhotite, while by etching, pyrrhotite is distinguished from pentlandite. By applying these distinctions, the following results have been obtained on the ores from the several districts above mentioned.

DETAILED STUDY.

THE SUDBURY DEPOSITS.

The literature of these deposits has been discussed by Dr. Barlow in his report[1] and summarized in his recent paper on their origin and relations.[2] The discussion as to origin is supported on one side by F. D. Adams, D. H. Browne, A. E. Barlow, A. P. Coleman, Baron von Foullon, J. F. Kemp, T. L. Walker and others who favor the igneous origin, and on the other by P. Argall, E. R. Bush, J. H. Collins, C. W. Dickson and others who uphold the secondary aqueous origin. The evidence brought forward by those who are thoroughly acquainted with the district and their subject seems all to point to an igneous origin. Yet Dickson[3] has a weight of evidence to prove that his specimens are of secondary aqueous origin. His work shows that the nickel occurs as pentlandite throughout; he works out the relationship between the sulphide and the gangue and con-

[1] *Loc. cit.*

[2] ECONOMIC GEOLOGY, I., pp. 454, 545.

[3] "The Ore-deposits of Sudbury, Ontario," *Trans. A. I. M. E.*, 1904, p. 3.

PLATE III.

Explanation of Figures.

Fig. 1. A view of chalcopyrite, *A*, cutting a mass of pentlandite, *B*. The difference in color is lost in the photograph. (× 88. V.) Creighton Mine, Sudbury.

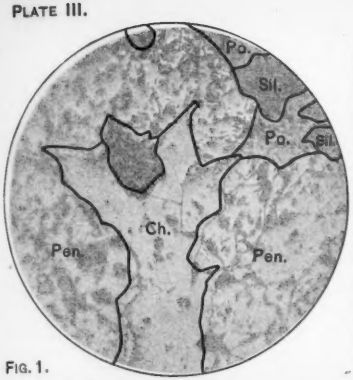
Fig. 2. Light-colored envelopes of pentlandite surrounding dark-etching grains of pyrrhotite. (× 88. V.)

Fig. 3. Same as 2. The light pentlandite shows its characteristic parting, and the dark pyrrhotite its roughness. (× 88. V.)

Fig. 4. Shows a dark mass of the silicates in which are embedded the lighter-colored sulphides. (× 88. V.)

Fig. 5. Same as 4, but shows two grains of magnetite with their differential etching. (× 88. V.)

Fig. 6. Shows two or more crystals of silicate along whose cleavages occurs the light yellow chalcopyrite. (× 88. V.)



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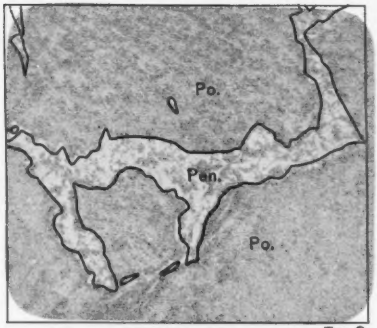

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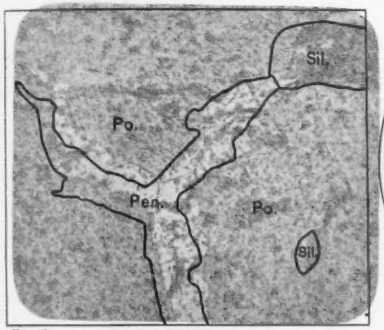

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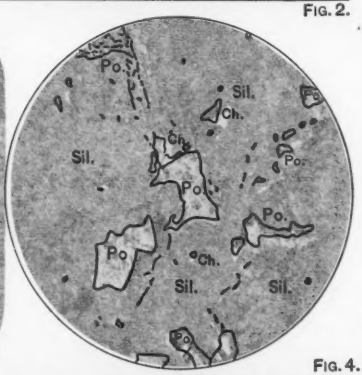

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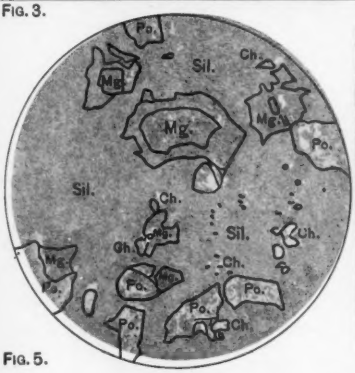

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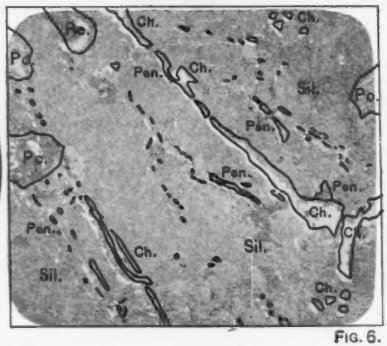


FIG. 6.

LEGEND.

Ch = chalcopyrite.	Py = pyrite.
Pen = pentlandite.	Mg = magnetite.
Po = pyrrhotite.	Sil = silicates.

cludes that owing " to the massive nature of the sulphides, very little can be accurately determined as to the paragenesis of the minerals," though it seems likely that the chalcopyrite is later than the pyrrhotite. By our method of work it has been possible for the writers to determine the order of origin to be (1) pyrrhotite, (2) pentlandite and (3) chalcopyrite in the specimens examined from the Copper Cliff, Gertrude, Creighton and Mount Nickel Mines and from the North Nickel belt.

The Creighton Mine.—The specimen consisted of chalcopyrite, pentlandite and pyrrhotite in more or less coarse grains. In one part a good deal of feldspar and pyroxene could be seen: this gangue we shall hereafter call silicate. Under the microscope, after etching, the pyrrhotite is seen as fairly large grains between which occur pentlandite and chalcopyrite. The latter are easily distinguished by color which however does not offer any contrast in a photograph, as can be seen in Plate III., Fig. 1, where a vein of smooth-polishing chalcopyrite, *A*, cuts into a mass of pentlandite, *B*, which is much more pitted. The contrast between the pentlandite and the dark-etching pyrrhotite is marked and is well shown in Plate III., Figs. 2 and 3. In general the pentlandite occurs as masses and veins between and around the grains of pyrrhotite. The structure is typically shown in Plate III., Fig. 2. These veins are not always continuous, but often die out, as is shown on the left of Fig. 3. With such a structure it seems evident that the pentlandite is later than the pyrrhotite. Associated with these pentlandite veins and masses, we find chalcopyrite. The association is so close that we must conclude that they are of the same generation. From the fact that in very many cases we find chalcopyrite cutting pentlandite, as shown in Plate III., Fig. 1, we conclude that the chalcopyrite is a little later than the pentlandite.

In addition we find fine lenses of pentlandite (and chalcopyrite) occurring with definite orientation within many of the pyrrhotite grains. They are presumably of the same age as the veins themselves, being often connected with them like stringers. The occurrence of such tiny lenses and flakes of pentlandite

PLATE IV.

Explanation of Figures.

Fig. 1. Three dark-etching rough grains of pyrrhotite separated by light envelopes of pentlandite. (× 50. V.) Copper Cliff, No. 2, Sudbury.

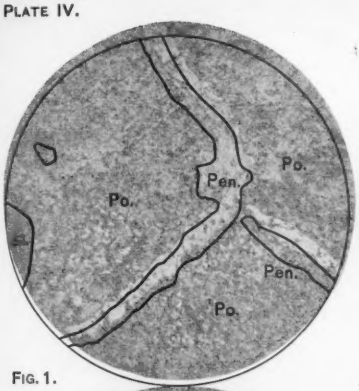
Fig. 2. A very deeply etched grain of pyrrhotite with its envelope of pentlandite which widens out into a mass with distinct parting. (× 50. V.)

Fig. 3. Dark etching pyrrhotite with a mass of light pentlandite and chalcopyrite. On the left are seen two rounded crystals of silicate. (× 50. V.)

Fig. 4. Dark etching pyrrhotite with a mass of light chalcopyrite at the top and of pentlandite at the bottom. The chalcopyrite occurs between two grains of silicate. (× 50. V.)

Fig. 5. Three grains of magnetite surrounded by a mass of smooth-polishing chalcopyrite on the left and rougher pentlandite on the right. (× 88. V.) Gertrude Mine, Sudbury.

Fig. 6. Dark etching grains of pyrrhotite full of inclusions. (× 50. V.) Mount Nickel, Sudbury.



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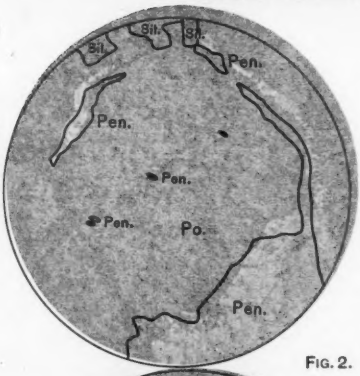

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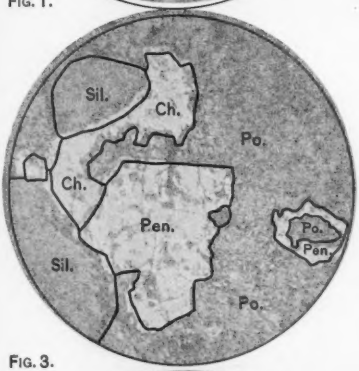

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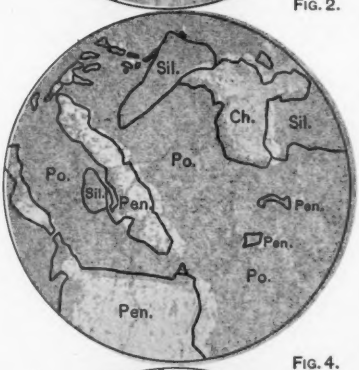

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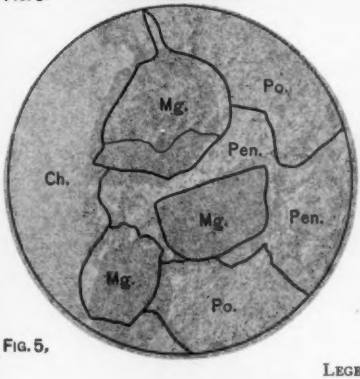

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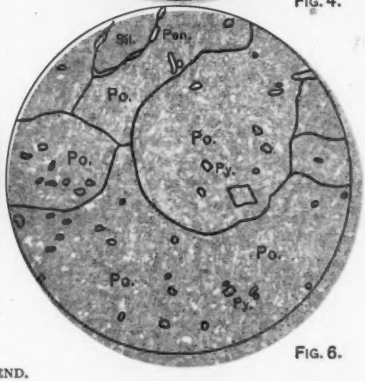

FIG. 6.

LEGEND.

Ch = chalcopyrite.
Pen = pentlandite.
Po = pyrrhotite.
Py = pyrite.
Mg = magnetite.
Sil = silicates.

within the grain of the pyrrhotite explains why a clean separation has proved impossible and this close association gives the reason for the belief that nickel replaced iron in "nickeliferous pyrrhotite." From the above we see that the order of origin was pyrrhotite, pentlandite, chalcopyrite.

A second specimen was examined and showed the same relations.

The relationship of the silicates, etc., to the sulphides has been worked out by C. W. Dickson,[1] whose micrographs 14 and 18 show the replacement of the former by the latter. In the present method of work the occurrence of the sulphides within the silicates is well shown. Plate III., Fig. 4, shows lighter grains of pyrrhotite occurring between and moulded on the silicate crystals. This is further shown in Fig. 5, whilst in Fig. 6 we have long veinlets of chalcopyrite (and pentlandite) traversing the silicates in definite orientation. In other parts of the field we find pyrrhotite and pentlandite penetrating and replacing the silicate, which when isolated is frequently strained and broken. Reaction zones are often seen. The occurrence of the magnetite is seen in Plate III., Fig. 5. Two grains of magnetite occur in the upper part of the field and when etched have developed their peculiar gridiron structure. The magnetite is evidently older than the silicates.

Hence we see that in the specimens examined a definite order is shown, as follows:

1. Magnetite.
2. Silicates.
3. Pyrrhotite.
4. Pentlandite.
5. Chalcopyrite.

The Copper Cliff Mine.—The specimen consisted of the coarse-grained pyrrhotite which contained pentlandite, and chalcopyrite together with magnetite and silicate. As before the pentlandite occurs as irregular veins around the large pyrrhotite grains, as seen in Plate IV., Figs. 1 and 2. It also occurs as more or less irregular masses which in some cases show a distinct cleavage or parting, as in Plate IV., Figs. 2 and 3. In addition tiny lenses

[1] *T. A. I. M. E.*, 1904, p. 36.

of pentlandite are found within the grain of the pyrrhotite itself, as already described in the specimen from the Creighton mine.

In the hand specimen the pyrrhotite shows a parting and under the microscope many of the grains show marked signs of strain.

The specimen contains a little chalcopyrite which occurs along with the pentlandite and is seen on the left of Fig. 3 and at the top of Plate IV., Fig. 4. In one or two places the pentlandite is cut by the chalcopyrite, which is therefore later. Magnetite occurs imbedded in the pyrrhotite as more or less rounded grains with a fine "gridiron" structure after etching. Crystals or grains of the silicate occur isolated in the pyrrhotite and show a rounding off of corners, as shown in Plate IV., Figs. 3 and 4, at the top of the photograph. These grains of silicate seem to be intimately associated with the chalcopyrite and often form a nucleus for it.

The structures met with in the specimen from Copper Cliff No. 2 are typically shown in Plate IV., Figs. 1 to 4, from which we see that the order is the same as in the ore from the Creighton, viz., magnetite and silicate, pyrrhotite, pentlandite and lastly chalcopyrite.

Gertrude Mine.—A small specimen was polished and etched and showed abundant chalcopyrite with pentlandite and pyrrhotite together with silicate, etc. Under the microscope the pyrrhotite is seen to be cut by veins of pentlandite and chalcopyrite. As before, the chalcopyrite cuts the pentlandite in several places.

Magnetite grains occur in the pyrrhotite, pentlandite and chalcopyrite. Plate IV., Fig. 5, shows three large grains of magnetite surrounded by a sulphide groundmass which on the left is smooth, well-polished chalcopyrite and on the right is more or less rough pentlandite.

The silicate occurs as rounded off grains in a mass of sulphide and is often strained. Occasionally the silicate includes magnetite, which then shows no rounding off of corners.

Here again we find the relations to be the same as before and we have the following order: (1) Magnetite, (2) silicate, (3) pyrrhotite, (4) pentlandite, (5) chalcopyrite.

Mount Nickel Mine.—A specimen[1] from this mine showed the relations of the later sulphides—galena, blende, etc.—in addition to those of the three main sulphides.

On etching, the specimen was seen to be composed of medium-sized grains of pyrrhotite shown in Plate IV., Fig. 6. The grains show signs of strain and are oriented in many cases with tiny cubes of what seems to be pyrite. The distinct orientation of the impurities in the pyrrhotite seems to show that they were thrown out in the solid. In any case they are enough to account for almost any variation in analysis.

Through the pyrrhotite runs a small vein about one fourth inch thick consisting of galena, blende, quartz and chalcopyrite in a symmetrical arrangement. The two outer walls are very thin and are composed of quartz, including a little blende and chalcopyrite. The center is broader and shows crystals of blende and a few grains of chalcopyrite in a quartz ground. Between the outer shell and the inner quartz core the vein is filled with galena. The whole seems to show that the central core of quartz, blende and chalcopyrite is a secondary vein in the galena.

Where the pentlandite and chalcopyrite occur they have their usual structure and order as in the previous specimens examined.

The North Nickel Range.—The specimen contains the three sulphides, magnetite and silicate together with much pyrite. On account of its hardness and toughness, the pyrite retains scratches long after the rest of the section is polished and it stands out in relief, which is more marked with continued polishing. This characteristic structure of the pyrite is well shown in Plate V., Fig. 1. As a rule, the corners of the pyrite are rounded off, though occasionally a more or less perfect cube is seen. Very often we find it broken up and the interstices filled with chalcopyrite, pyrrhotite, etc. Plate V., Fig. 1, shows several grains of pyrite between which is a later groundmass of chalcopyrite. In places patches of dark silicate are seen, also penetrated by the chalcopyrite.

The silicate contains veins and small masses of pyrrhotite and

[1] Dickson, *Trans. A. I. M. E.*, 1904, p. 5, l. 19.

PLATE V.

Explanation of Figures.

Fig. 1. Rough, badly scratched pyrite cemented by chalcopyrite. The two black masses are silicate. (× 88. V.) North Nickel Range, Sudbury.

Fig. 2. A mass of dark silicate impregnated with chalcopyrite. Three grains of pyrite occur in the lower part of the field. (× 88. V.)

Fig. 3. Dark pyrrhotite with lighter pentlandite. The black crystals are silicate. (× 50. V.) Flaad Mine.

Fig. 4. The main mass is dark-etching pyrrhotite. In the center of the field is a broken silicate crystal associated with pentlandite and chalcopyrite. (× 50. V.)

Fig. 5. The upper half shows dark-etching pyrrhotite and the lower half bright chalcopyrite. (× 50. V.) Erteli Mine No. 2.

Fig. 6. On the right is dark pyrrhotite with thin veins of pentlandite. At the bottom occurs a mass of bright chalcopyrite, while on the left is a mass of silicate, including black magnetite. (× 50. V.)

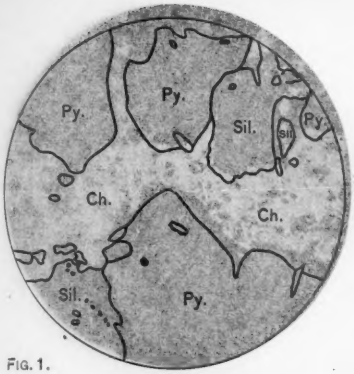

FIG. 1.

FIG. 2.

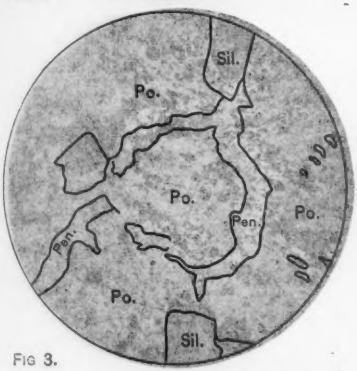

FIG 3.

FIG. 4.

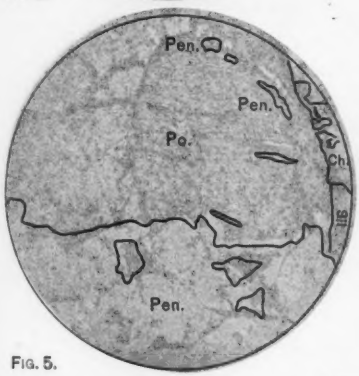

FIG. 5.

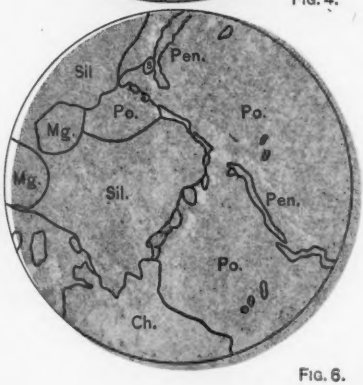

FIG. 6.

LEGEND.

Ch = chalcopyrite.	Py = pyrite.
Pen = pentlandite.	Mg = magnetite.
Po = pyrrhotite.	Sil = silicates

chalcopyrite, which in Plate V., Fig. 2, is seen as irregular veins and ramifications clearly replacing the silicate. Some pentlandite was seen as veins in the pyrrhotite. The magnetite is clearly the oldest mineral present, being found inclosed both in pyrite and in silicate.

The relation of the pyrite to the silicate is not very clear. They are both certainly older than the three sulphides and from the mode of occurrence of the pyrite it seems likely that it was an original constituent of the rock, before the advent of pyrrhotite, chalcopyrite, etc. Thus we have the order of origin: (1) Magnetite, (2) pyrite and silicate, (3) pyrrhotite, (4) pentlandite, (5) chalcopyrite.

SUMMARY ON THE SUDBURY SPECIMENS.

In all of the specimens examined we find a definite order of origin: (1) Pyrrhotite, (2) pentlandite, (3) chalcopyrite, together with certain characteristic structures, for the sulphides. Of the original rock matter, magnetite is the earliest constituent. Pyrite, when it occurs as in the North Nickel Range, is probably also an original constituent. At all events it was present in the rock before the deposition of the pyrrhotite.

It would seem that the pyrrhotite was in turn strained and pentlandite and then chalcopyrite deposited between its grains (and also within the parting of the grains themselves) in places by replacement.

The resulting structures are shown in Plate III., Figs. 2 and 3, and Plate IV., Figs. 1, 2, 3 and 4. The fracturing of the silicates and their replacement by and inclusion of the three sulphides is shown in Plate III., Figs. 4, 5 and 6.

THE NORWEGIAN DEPOSITS.

The Scandinavian nickel deposits have been described by Professor Vogt, of Christiania, in great detail and resemble those of the Sudbury district. They are given as examples of segregations from igneous magmas, for the ore bodies are closely associated with masses of gabbro or norite. The ore is chiefly composed of pyrrhotite, with which is associated chalcopyrite and pyrite. Pentlandite has been recognized.

PLATE VI.

Explanation of Figures.

Fig. 1. Very deeply etched pyrrhotite grains, surrounded by thin envelope of light pentlandite. (× 50. V.) Sohland.

Fig. 2. A mass of light pentlandite and chalcopyrite grains set in dark pyrrhotite. (× 50. V.)

Fig. 3. Grains of light pentlandite and silicate crystal in a mass of very deeply etched pyrrhotite. (× 50. V.) St. Stephen, N. B.

Fig. 4. The upper half consists of deeply etched pyrrhotite, the lower is a silicate crystal broken and cemented by pyrrhotite, pentlandite and chalcopyrite. (× 50. V.)

Fig. 5. Very deeply etched pyrrhotite with light veins of pentlandite. (× 50. V.) Gap Mine, Pa.

Fig. 6. Very deeply etched pyrrhotite between the grains of which occurs a mass of chalcopyrite and pentlandite. In addition numerous small crystals of silicate are seen. (× 50. V.)

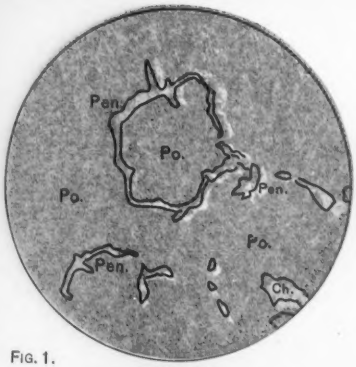

FIG. 1.

FIG. 2.

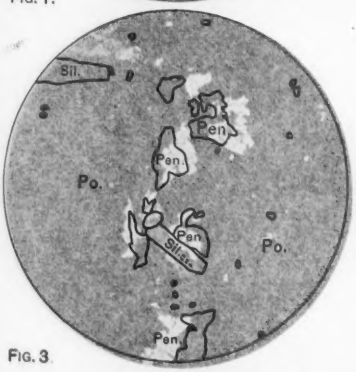

FIG. 3

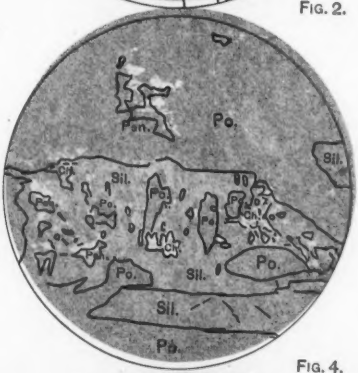

FIG. 4.

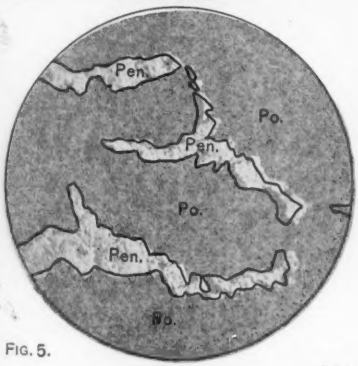

FIG. 5.

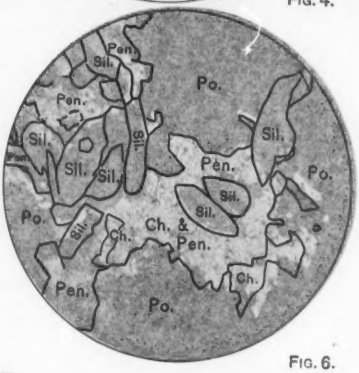

FIG. 6.

LEGEND.

Ch = chalcopyrite.	Py = pyrite.
Pen = pentlandite.	Mg = magnetite.
Po = pyrrhotite.	Sil = silicates.

Specimens were obtained of the ore from the Flaad and Erteli mines and examined in the same manner as those from Sudbury.

The Flaad Mine.—The specimens examined consisted of the massive ore. The first consisted of small grained pyrrhotite with well-marked envelopes of pentlandite which in places thicken out into masses showing the usual parting. Fig. 3, Plate V., shows small grains of dark etching pyrrhotite surrounded by lighter pentlandite. In addition broken grains or crystals of silicate are seen. All of the silicate is badly shattered and when it occurs in a groundmass of pyrrhotite, it shows a rounding of the angles. Magnetite is often included within the silicate. As before the chalcopyrite is later than the pentlandite and favors the neighborhood of the silicates, especially when the latter are badly broken up, in which case they generally contain many ramifications of the sulphides.

In another specimen of medium-sized grain, the whole of the pyrrhotite is apparently strained. It contains numerous fine lenses of pentlandite (and chalcopyrite) definitely oriented. The pentlandite occurs as thin veins to thick masses. The chalcopyrite occurs in large masses of pentlandite and also favors the broken-up silicates occurring along their lines of fracture.

The silicates include grains of magnetite and have zones replaced by chalcopyrite, etc. Fig. 4, Plate V., shows a crystal of silicate set in a mass of dark etching pyrrhotite. The silicate is badly fractured and filled with chalcopyrite and pentlandite which show up lighter than the rest. In the center a dark grain of magnetite is seen.

Thus we see that the order is the same as that at Sudbury, viz., (1) magnetite, (2) silicates, (3) pyrrhotite, (4) pentlandite, (5) chalcopyrite.

The Erteli Mine, No. 2.—The first specimen consists of coarse-grained pyrrhotite associated with chalcopyrite and a little pentlandite. The pyrrhotite has been strained and etches differentially, while to the eye it has a pearly appearance. The pentlandite occurs as thin veins and as fine lenses in the pyrrhotite but no masses of it were seen. The chalcopyrite, on the other

hand, is found as masses and thick veins, associated with small amounts of pentlandite. Plate V., Fig. 5, shows the strained grains of pyrrhotite with the thin veins of pentlandite. At the bottom of the section a large mass of chalcopyrite is seen. This structure is characteristic of the specimen. Magnetite occurs as rounded grains while the green silicate is broken up and in many cases fibrous.

A second specimen showed coarse-grained pyrrhotite similarly cracked and strained. As before fine inclusions of pentlandite occur along such cracks. The pentlandite also occurs as veins and small masses round the pyrrhotite grain. Chalcopyrite as before is found in masses of considerable size and also as veins, some of which have a marked serrated edge. A green silicate occurs very much broken up whilst in one place is seen a mass of quartz. Plate V., Fig. 6, shows two grains of dark etching pyrrhotite on the right, surrounded by thin veins of pentlandite, while at the bottom is seen a mass of chalcopyrite. On the left we have a mass of silicate (probably quartz), including several black grains of magnetite.

Again we have the same order as that at Sudbury, magnetite, silicate, pyrrhotite, pentlandite, and last chalcopyrite. The structures met with are also remarkably similar as is seen when we compare Plate III., Fig. 2, with Plate V., Fig. 3, or Plate IV., Fig. 2, with Plate V., Fig. 5, whilst the similar occurrence of pentlandite as fine lenses with definite orientation within grains of apparently strained pyrrhotite is noteworthy.

THE DEPOSITS OF SOHLAND, SAXONY.

The geology of these nickel deposits has been described by Beck.[1] They occur in the so-called Lausitzer granite and are closely associated with diabase dykes, consisting chiefly of plagioclase, augite, brown hornblende and brown mica. The granite often shows the effects of metamorphism. The ore consists of nickeliferous pyrrhotite with chalcopyrite and pyrite, which are of secondary origin. C. W. Dickson[1] corroborated Beck's results but was unable to find in what form the nickel occurred.

[1] "Die Nickelerzlagerstätte von Sohland," *Zeit. der Deutsch Geol. Gesell*, 1903.

The specimen we examined showed a banded structure due to the arrangement of the pyrrhotite and the chalcopyrite. On etching we were able to distinguish pentlandite, which occurred in the pyrrhotite as extremely thin veins round small grains of pyrrhotite, and as very small grains associated with much chalcopyrite. In addition it occurred as minute flakes within the pyrrhotite grains. Plate VI., Fig. 1, shows the characteristic vein structure and consists of light pentlandite set in a deeply etched groundmass of pyrrhotite. Plate VI., Fig. 2, shows the mass of fine grains of pentlandite intimately mixed with chalcopyrite, the whole set in the darker pyrrhotite. This occurrence of pentlandite as very thin veins and small grains, etc., explains why it cannot be separated from the chalcopyrite and pyrrhotite.

The chalcopyrite occurs as comparatively large elongated masses in pyrrhotite.

Whilst the pyrrhotite is clearly older than the pentlandite and chalcopyrite, the relative ages of the two latter are not very clear. The structures as a whole, however, seem to point to the chalcopyrite being later. If this is so we have the same order of origin as in the case of the Sudbury and the Norwegian deposits, viz., pyrrhotite, pentlandite and chalcopyrite.

THE DEPOSITS OF ST. STEPHEN, N. B.

The country consists of diabases and diorites, with which are associated masses of nickeliferous pyrrhotite and chalcopyrite. The area has been greatly metamorphosed. Dickson[1] made a careful microscopic study of the ore and came to the conclusion that the deposits are *not* the result of a direct segregation from an original magma but are of a secondary nature deposited from circulating solutions by a metasomatic replacement of the rock minerals. He found that the pyrrhotite at first probably formed the larger portion of the ore, and chalcopyrite has been introduced still later.

The specimen we examined was of massive pyrrhotite, extremely fine-grained to the eye. Under the microscope this pyrrhotite is either very fine-grained or has been broken up. It

[1] "Genetic Relations of Nickel-Ores," *Journal Canadian Institute*, Vol. IX.

polishes extremely rough. On etching pentlandite is seen to occur as small, irregular grains which is characteristic of the chalcopyrite also. Plate VI., Fig. 3, shows this structure very well. The absence of the vein structure is noteworthy.

Very many crystals or grains of magnetite occur. They etch with their characteristic structure. Several different silicates can be distinguished. The crystals are more or less fractured and include pyrrhotite. Chalcopyrite also favors the shattered silicate crystals, in places replacing them. This occurrence is typically shown in Plate VI., Fig. 4. The upper half of the photograph shows dark etching pyrrhotite with a stray grain of pentlandite. The lower half consists of a large silicate crystal which is more or less broken up and replaced by both dark etching pyrrhotite and chalcopyrite.

Owing to the mode of occurrence the relative ages of the chalcopyrite and pentlandite are uncertain; they are both younger than the pyrrhotite, however. We can, therefore, be sure of the order, magnetite, silicates, pyrrhotite and pentlandite and chalcopyrite.

THE GAP MINE, LANCASTER CO., PA.

The ore occurs along the junction of a large lenticular mass of amphibolite with the enclosing mica-schist, and is mainly pyrrhotite. Kemp,[1] from the resemblance to the Sudbury deposits and some of the Norwegian ores, concludes that the ore body was formed by differentiation from the igneous magma and as such is an original crystallization. He follows the views of Vogt on the origin of such ore-bodies.

A specimen of the ore was polished and examined. It was found to be composed of medium-sized grains of pyrrhotite, which were apparently badly strained. Around the pyrrhotite, as veins and as masses, pentlandite was seen with its characteristic cleavage. Chalcopyrite occurs closely associated with the pentlandite and is most probably later, being molded against it and including grains of it. Besides the three sulphides, magnetite occurs as octohedra and silicate as prismatic crystals with ragged termination, resembling hornblende. In Plate VI., Fig.

5, we have the light colored pentlandite as irregular veins round the very deeply etched grains of pyrrhotite. In Plate VI., Fig. 6, the dark groundmass is composed of pyrrhotite and between its grains occurs a mass of pentlandite and associated chalcopyrite. In addition numerous crystals of silicate can be seen. As before where the silicate is badly fractured it is often cut and replaced by chalcopyrite.

Thus in the case of the Gap mine we find the order to be the same as before: Magnetite and silicate, pyrrhotite, pentlandite and chalcopyrite.

CONCLUSIONS.

From this metallographic examination of nickel ores from widely distant localities we find many striking points of similarity.

1. The ore is composed of the three sulphides, pyrrhotite, pentlandite and chalcopyrite.

2. These sulphides occur in a definite order:

I. Pyrrhotite,

II. Pentlandite,

III. Chalcopyrite.

3. The pentlandite and chalcopyrite are closely associated and have a habit in common.

4. The occurrence of magnetite as the earliest consituent present, and of crystals and grains of silicates as the next oldest constituents.

5. The general rounding off and smoothing of angles and frequent fracturing of these silicates and the intrusion within them and replacement by the sulphides.

All of the ore-bodies are associated with basic eruptives.

The natural explanation would be that the mode of origin of all was the same. The basic rocks were more or less fractured and ore-bearing solutions came in and replaced the rock-matter wholly or in part by pyrrhotite. Later on the pyrrhotite, etc., was also strained and broken, and the deposition of pentlandite and chalcopyrite followed, the pentlandite precipitating before the chalcopyrite.

This explanation has been rejected in favor of the theory of segregation from igneous fusion by those who are not only masters of their subject but also thoroughly acquainted with the geology of the ore-deposits themselves. By such geologists a widely different interpretation may be put upon our work.

Our main object, however, was to determine the order of origin of the chief components of the various ore-bodies, and this we have done, as shown in the above work, which we offer as a contribution to that rapidly growing science, economic geology.

In conclusion, our thanks are due to Professor James F. Kemp and Dr. Berkey, of Columbia University, and Dr. C. W. Dickson, School of Mining, Kingston, Ont., who very kindly supplied us with material. The thanks of one of us are also due to the Carnegie Institution of Washington for a grant for apparatus.

MAGNETIC OBSERVATIONS IN GEOLOGICAL AND ECONOMIC WORK. I.

HENRY LLOYD SMYTH.

In September, 1896, I published in the *Transactions of the American Institute of Mining Engineers* a paper on "Magnetic Observations in Geological Mapping," which was afterwards reprinted with certain changes in *Monograph* XXXVI, of the U. S. Geological Survey series. In these articles, after taking up at some length the theory of the dial-compass and dip-needle, I described the manner in which concealed magnetic rocks might be mapped by means of magnetic observations with these instruments. Of late years, and especially since the appearance of the works of Dahlblom-Uhlich[1] and of Haanel,[2] describing the methods of magnetic surveying with the Swedish magnetometer, I have frequently been asked about the relative merits of these instruments and methods; for example, whether the Thalén-Tiberg or Swedish magnetometer is not a better instrument than the dial-compass and dip-needle; or whether the dial compass and dip-needle are not better than the magnetometer; or what the fields are to which the two sets of instruments are respectively better adapted. In this present article I shall try to answer these questions; first, as an indispensable preliminary, explaining as clearly as possible what observations are made with these instruments, how the observed quantities are related to the forces of the magnetic field, and how the position of the magnetic material may be inferred from the observations.

At the outset it will be helpful to understand in what kinds of work these instruments have actually been employed; broadly, it may be said that the dial-compass and dip-needle have gener-

[1] "Ueber magnetische Erzlagerstätten und deren Untersuchung durch magnetische Messungen," von T. Dahlblom; ubersetz v. P. Uhlich, Freiburg, 1889.

[2] "On the Location and Examination of Magnetic Ore-deposits by Magnetometric Measurements," by Eugene Haanel, Ottawa, 1904.

ally been used in the rapid survey of extended magnetic formations of stratified character, while the magnetometer, both in this country and in Sweden, has generally been used to cover closely small areas in which magnetite occurs in a highly concentrated state. The essential difference between these two conditions is that a long and relatively narrow belt of magnetic rock cannot possibly be regarded as having its magnetic force ema-

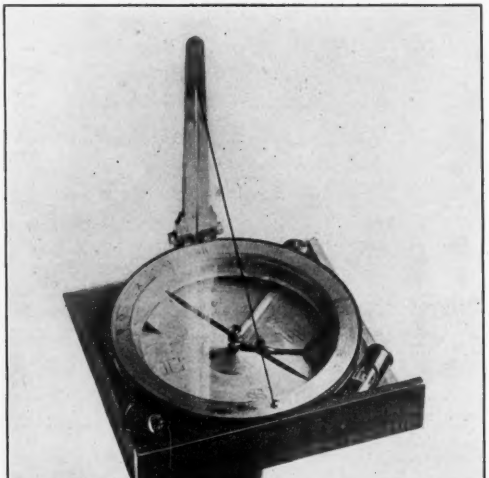

FIG. 37. Dial-compass.

nating from two fixed points or poles, but must be regarded as a magnetized strip,[2] while a small body of rich magnetic ore is less obviously unlike the familiar bar magnet, and in fact, in order to explain the theory of the magnetometer, is assumed by all writers to behave like a bar magnet with two fixed poles.

[2] *Transactions American Institute of Mining Engineers,* Vol. XXVI., 1896, pp. 645-8.

Of course the final object of the survey is to locate the disturbing matter, that is to say, to define its boundaries and to determine its depth. Clearly, before any conclusions can be drawn from the deflections observed in the magnetic instruments, it is necessary to understand their construction, and the manner in which the forces of the field act upon them.

THE DIAL-COMPASS.

1. *Construction and Uses.*—The dial-compass (Fig. 37) is a small, portable sun-dial provided with a compass needle swinging inside a graduated circle, which, when the instrument is level, is horizontal. On a sunny day, if this instrument is set up, levelled, and turned in azimuth until the shadow of the gnomon (a thread) falls on that division of the hour-circle which corresponds to the apparent time, the zeros of the graduated circle will be in the true meridian, and the declination of the magnetic needle may be read off directly. In order that the instrument may be set in the meridian and the correct declination read, several things are necessary; it must be properly constructed, that is to say, the hour circle must be graduated for a latitude near that of the place of observation, the gnomon must make with the plane of the hour circle an angle equal to the latitude of the place, and the zeros of graduation must be in the vertical plane of the gnomon; the plane of the hour-circle must be level; and the apparent time must be known. To obtain apparent time requires two corrections to standard time; first, a correction for the difference of longitude between the place of observation and the standard meridian, and secondly, the addition or subtraction of the equation of time, taken from the Nautical Almanac for the proper day and year.

As a magnetic instrument, the sole purpose for which the dial-compass is employed is to determine the declination or deflection of the horizontal needle at the several stations of observation; but it is hardly less useful as a self-contained surveying instrument by means of which the true meridian and consequently any other direction may quickly be ascertained no matter how much the compass is disturbed.

2. *Deflections of the Horizontal Needle.*—From the construction of the dial-compass, it is evident that the pointing of the magnetic needle within its graduated circle is affected by only the horizontal forces of the magnetic field; a vertical force may depress or elevate the north end of the needle, but cannot change its position in the horizontal plane. Away from local disturbance that position is determined by the direction of the horizontal component of the earth's force, which, although subject to small diurnal fluctuation and to progressive annual and secular change, may be regarded for our rough purposes as constant during the brief periods and over the small areas with which we have to do,—the times and places of special geological and economic investigations.

In the presence of local magnetic matter the dial-compass or horizontal needle no longer remains in the magnetic meridian, but is deflected from it. The magnetic matter attracts one pole and repels the other (since the needle is very small) with sensibly equal force. The final position assumed by the needle depends on the direction and amount of the horizontal component of this force, and is the line of the resultant of this horizontal component and the horizontal component of the earth's magnetism. The declination or deflection of the needle is then the angle which this resultant makes with the true or with the magnetic meridian, respectively, and this angle is read at each station of the survey.

The important points to be located by the horizontal needle in all magnetic surveys are first, the points at which the horizontal component of the disturbing force becomes zero, and secondly, the points at which it has a maximum value. The relation of these important points, which may be named the *critical points*, to the deflections of the horizontal needle, and their position with regard to the disturbing matter, are best explained by the consideration of two partly ideal cases.

3. *Deflections Produced by a Single Pole.*—First, let us consider a single magnetic pole possessing north polar magnetism; it may be regarded as the upper pole of a vertical bar magnet so long that the lower (south) pole is too far away to affect the compass. The angle of deflection of a compass needle observed

at various stations in a horizontal plane above this pole will evidently depend upon or be a function of two variables; one, the distance of the point of observation from the pole, and the other, its direction from the pole. The distance affects the nu-

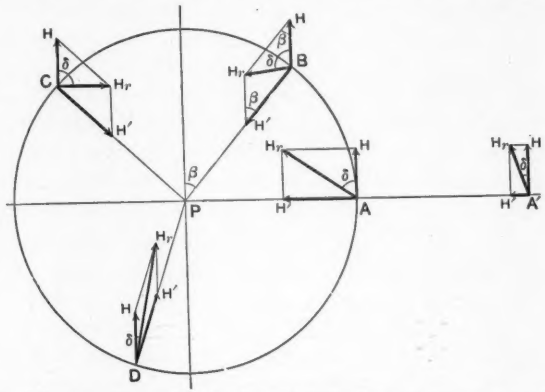

FIG. 38. Diagram illustrating horizontal deflections of compass needle due to a single pole.

merical value of the horizontal component of the force of the disturbing pole, while its direction affects the angle which this component makes with the magnetic meridian. If the distance is constant, that is to say, at all points on a circle drawn about *P* as a center (Fig. 38), the angle of deflection will vary with the direction only. If the direction is constant, that is to say, at all points on a straight line passing through *P*, the angle of deflection will vary with the numerical value or intensity of the horizontal component, that is, with the distance of the point of observation from the pole. These principles are illustrated in Fig. 38.

The four stations, *A, B, C, D,* are in the same horizontal plane and are equally distant from the pole *P,* which therefore exerts an equal attraction on a horizontal needle observed at each of them in turn. The parallelograms of force at these stations show the manner in which the deflection of the needle is dependent on the direction of the station of observation from the

attracting material. The horizontal component, H, of the earth's magnetism is the same in amount and direction at each station; the horizontal force, H', of the pole is the same in amount, but (since it always points towards the pole) is different in direction at each of these stations; the angle of deflection, δ, therefore varies with the direction of H'. On the other hand at a station A' in the line PA, H' has the same direction as at A, but is smaller, since A' is farther from P. At A', therefore, δ is smaller than at A because of the diminution in H'.

The same fact may be expressed algebraically. From any of the parallelograms, for example, that at B, we obtain the following simple relation between the angle of deflection, δ, the angle of direction of H', β, and the two horizontal forces H and H', and their resultant, H_r:

$$\frac{H}{\sin(\beta+\delta)} = \frac{H'}{\sin\delta} = \frac{H_r}{\sin\beta}$$

$$\tan\delta = \frac{\sin\beta}{\frac{H}{H'} - \cos\beta} \qquad (1)$$

These considerations make it clear that the angles of deflection may serve to measure changes in the intensity of H', if the direction of H' remain constant throughout the series of observations which are to be compared. In order that the direction of H' may remain constant,—that is to say, in order that changes in the angle of deflection due to changes in the direction of H' may be eliminated,—all the observations of each series must be made along a straight line passing through P. In such a series the angle of deflection increases or diminishes with H',—if it becomes zero, H' also becomes zero; and its maximum value corresponds to a maximum value of H'.

What is the position with regard to the disturbing matter of the critical points at which these values are attained? Let us consider a series of observations made along the straight line PA' (Fig. 38), shown as OA' in vertical section in Fig. 39.

At any station of observation such as A, the pole P exerts a force F which acts along the line PA. If the angle OPA be

designated as ϕ the horizontal component of this force is

$$H' = F \sin \phi.$$

The force F varies inversely as the square of the distance PA of A from P. If K is the force exerted by P on the magnetic needle in question at unit distance, and h is the depth OP of the pole P below the plane of observation, we may write

$$F = \frac{K}{PA^2} = \frac{K}{h^2} \cos^2 \phi$$

$$H' = \frac{K}{h^2} \sin \phi \cos^2 \phi \qquad (2)$$

From equation (2) it is evident that the critical points are fixed by the following considerations: (1) when ϕ equals zero,—when the station of observation is at O directly over P—H' becomes zero, and the angle of deflection becomes zero also; (2)

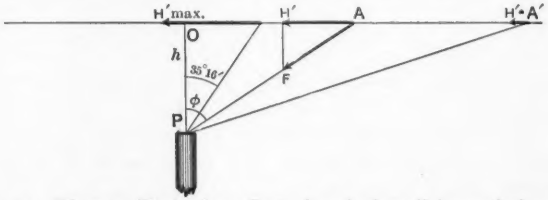

FIG. 39. Diagram illustrating effect of a single poll in vertical section.

since for large values of ϕ, that is to say, remote stations of observation, $\cos^2\phi$ becomes very small, there must be some intermediate value of ϕ for which H' and the corresponding angle of deflection will have maximum values. It is easy to show that this value of ϕ is 35° 16′.

This relation holds for all vertical sections through P. Therefore a circle with P as center and radius h tan 35° 16′ will contain all the points at which H' is a maximum. Moreover, the radius of this circle is determinable by trial on the ground since by making a sufficient number of observations along any cross section, the points where H' equals zero (over P), and where

H' is a maximum are easily found. The distance, d, between them being known, h, the depth, is at once determined from the relation

$$h = d \text{ ctn } 35^\circ\ 16' = d\sqrt{2} = 1.4d.$$

The importance of the determination of the critical points—the points at which H' equals zero and has maximum values—is now evident. In the simple case just considered, the point where H' equals zero is directly over the point from which the magnetic force emanates—that is to say, the pole—which it therefore serves to locate on the map; while the additional determination of a single point at which H' is a maximum gives an easy means of finding the depth of that pole below the plane of observation.

4. *Deflections Produced by a Magnetic Strip.*—It is, however, obvious that the magnetism of magnetic rocks cannot adequately be represented by so simple a conception. Experience in the field shows that their magnetism has the following general characteristics: (1) Their magnetic force is not concentrated at two fixed poles but is distributed over or near their surfaces, the upper surface having the same kind of magnetism as the north magnetic pole of the earth and invariably attracting the north-seeking end of the compass needle, while the lower surface has south polar magnetism; (2) when magnetic rocks dip very steeply their lower surfaces, which possess south polar magnetism, are sunk so far beneath the plane of observation as not to affect magnetic observation made upon it; (3) the intensity of their magnetic force varies with the quantity of magnetite which they contain, with its arrangement, and with the direction of their strike and dip, being greatest for rocks which dip in the direction of the earth's force and least for rocks which dip at right angles to this direction.

Magnetic rocks present the greatest variety of attitude and form. Frequently, however, they occur as tilted stratified (or stratiform) formations, which, when platted, appear on the map as long and relatively narrow strips. Some strips of this sort in the Lake Superior region are 20 miles or more in length, and

not more than 1000 feet or so wide. Among the many causes of disturbances in the earth's magnetic field the magnetized strip is therefore a type well marked and by no means rare. Let us assume that such a strip, of uniform width and very long in proportion, runs straight, dips vertically, has a level upper surface over which magnetism is uniformly distributed, and is covered to a uniform depth by a concealing mantle of sand. Of course no actual magnetic rock perfectly fulfiills these assumed conditions of uniformity. It is an ideal case; at the same time it may be said that some formations are known in which most of these assumptions are fairly closely realized.

The important characteristic of a straight and very long strip, uniformly magnetized and of uniform width, is that H', the horizontal component of its force, acts at right angles to the strike of the rock—that is to say, in parallel lines—over the whole field. Its direction at all stations on the same side of the rock is the same; while at stations on opposite sides of the rock its direction differs by 180°. Consequently, on the same side of the rock, the deflection of the needle varies only as the numerical value of H', and is therefore a direct measure of H'. In any series of observations made on a straight line crossing the strip, wherever the angle of deflection is zero (except where the strip strikes east and west) there H' must be zero also; and wherever the angle of deflection is a maximum, H' also must be a maximum.

The actual numerical value of the deflections of the horizontal needle will of course depend on the strike or orientation of the strip. A strip which strikes east and west (magnetic) will produce no deflection of the horizontal needle except on its north side, at those stations (if any) at which H' is numerically greater than H. A strip which strikes north and south (magnetic) will produce equal deflections on both sides at stations equally distant. A strip which strikes northeast or northwest will produce greater deflections at stations on its northern side than at the corresponding stations on its southern side, as readily appears from Fig. 40.

Take two stations P and P' at equal distances from the strip (which strikes northeast) but on opposite sides. H' is equal but acts in opposite directions at those stations. The parallelograms of force at the two stations are equal, H_r at P is the long diagonal, and H_r' at P' is the short diagonal of this parallelogram. The angles of deflection δ and δ' at the two stations are opposite the short and the long semi-diagonal respectively, and hence δ is smaller than δ'. The same relation evidently holds for all other pairs of stations in the two divisions of the field.

Where are the critical points situated? What is the position with reference to the strip of the points at which H' equals zero, and of the points at which H' is a maximum? To answer these questions requires a somewhat long analysis which may be found in the paper[1] already referred to. I shall only repeat the results here.

1. The points at which H' equals zero are situated over the middle of the strip; the line joining them is in its median plane

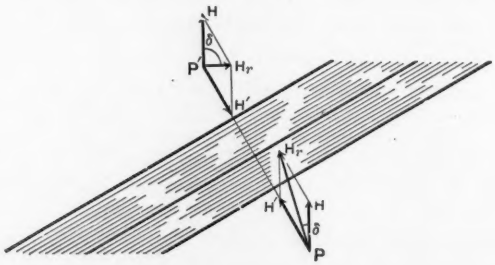

FIG. 40. Diagram illustrating horizontal deflections of compass needle due to magnetic strip.

and therefore gives its strike. This line is called a magnetic line. All points on the magnetic line (except where the strip strikes east and west, when they are indeterminate) may be found from the fact that they are the points at which there is no deflection of the horizontal needle.

2. The points at which H' is a maximum are determined by

[1] *Trans. Am. Inst. Min. Eng.*, Vol. XXVI., 1896, pp. 656–9.

the fact that they are the points at which the angle of deflection is a maximum; they occur in two lines—called maximum lines—one on each side of the strip and equidistant from the magnetic line. If d is the distance of a point on the maximum line from the magnetic line, h the depth of cover over the strip, and $2a$ the thickness of the magnetic formation (or the width of the strip), then these quantities are connected by the following simple relation:

$$d^2 = h^2 + a^2. \qquad (3)$$

d is determined by the magnetic survey (by finding half the distance between the points of maximum deflection on a normal cross-section) and may be measured on the ground; consequently if a is known the depth becomes known. The relation between a known value of d and the other two quantities a and h, is shown in Fig. 41 below.

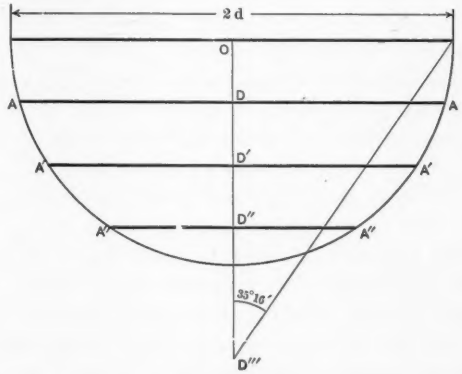

FIG. 41. Diagram showing relation between width and depth of magnetic strip.

In the semi-circle the horizontal diameter is $2d$. Corresponding to this value of d the magnetic strip may have any width $2a$ between $2d$ and zero equal to the length of any of the possible parallel chords of the semi-circle, while the depth is given in each case by the length of the perpendicular let fall from the centre to that chord. For example, if the width of the strip is AA its depth is OD; or if $A'A'$ or $A''A''$, the depth is OD' or OD'' re-

spectively, the limit being reached when the width of the strip is reduced to a line, in which case the depth becomes d. But in all cases the depth is less than OD''', the depth obtained by assuming the magnetic force to emanate from a single pole.

3. If the magnetic strip represents not a vertical rock but one inclined from the vertical, I have shown that if d is half the distance between the maximum points on a normal cross section and Δ is the angle of dip

$$d^2 = \frac{h^2 + a^2}{\sin^2 \Delta} \tag{4}$$

which of course reduces to equation (3) when $\Delta = 90°$. In this case,—namely where the rock is inclined less than 90°—the point of no horizontal deflection, corresponding to H' equals zero, is not half-way between the points where H' has maximum values, but is always nearer the maximum towards which the rock dips. Therefore this gives us a means of determining the direction of dip of an inclined rock.

4. But the finding of the points where H' is a maximum, and where it becomes zero, that is to say, the critical points, not only enables us to determine the strike, the direction of dip and depth of the magnetized strip; it also enables us to draw its boundaries, or at least to define closely the limits within which they must lie. As Fig. 41 and equations (3) and (4) show, the width of the strip can never exceed $2d$; also, when the dip is vertical, both boundaries must lie inside the maximum lines. When the dip is less than 90°, but not very low, the lower boundary falls inside one maximum line, while the upper boundary is between the magnetic line and the other maximum line.

With magnetic masses of other forms, and especially of more restricted dimensions, assumed to have a uniform surface distribution of magnetism, the determination of the relation between the critical points, the dimensions of the deposit, and its depth presents considerable analytical difficulties; and probably these relations are not simple. From the analogy of the strip, however, it is probably safe to conclude: (1) That the maximum points will fall outside of and probably not very far away from

the boundary of the magnetic body, if that body has a steep dip; (2) that inequalities in the distance from the magnetic line to the maximum lines indicate the direction of dip; and (3) that the depth is very much less than that obtained by supposing the deposit to be a single magnet.

Such are the observations made with the dial-compass, and the inferences as to the position and boundaries of the disturbing matter which may be drawn from these observations. In the next article I shall take up the magnetometer and, after describing the essential features in its construction and the manner in which it is used as a horizontal instrument, I shall consider the principles on which the observations and their interpretation depend.

THE ORE-DEPOSITS OF COPPEROPOLIS, CALAVERAS CO., CALIFORNIA.

JOHN A. REID.

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LOCATION.

The town of Copperopolis, in and near which lie the copper deposits to be discussed in this paper, is situated in Calaveras County, California, about forty miles east of the city of Stock-

ton. A branch railroad runs from the last named place to the town of Milton, from which it is fourteen miles by stage to the copper town. The locality is a portion of the copper belt of the foothill region of the Sierra Nevada, which extends for one hundred and fifty miles from southeast to northwest. This belt is in turn a part only of the larger copper belt of California, which is roughly four hundred miles long, paralleling the crest of the Sierra Nevada. Two other copper-producing mines lie to the north in Calaveras County the Penn Company property at Campo Seco, and the Poole Mine, nine miles distant on the stage road from Milton to Angel's Camp. A number of promising copper properties are also situated in the region just west. The middle belt of the famous Mother Lode system lies twelve miles to the east, and the west belt of the same system is two miles to the west. All these belts extend northwesterly and southeasterly for many miles. Supplies are brought in to Copperopolis from the railroad by team and traction engine; the oil used in smelting is delivered entirely in the latter way. It is merely a question of time until rails are laid directly to the mine.

The south bounding line of the Jackson sheet of the U. S. Geological Survey, to which other reference will be made, is only about two and a half miles to the north. The areal geology around Copperopolis has never been mapped.

TIME OF EXAMINATION.

The examination of this copper deposit was begun in the spring of 1906, and completed by work at different times until September of the same year. The ore deposit as a whole is of the greatest interest, and some features are peculiar and rather novel. No geologic work of detailed nature has heretofore been done on this property, and this paper aims to compass two ends: first, to set forth the exact nature of the ore-deposit in a short paper; and, second, to show the possibilities and need of such work in the proper development of a mine.

This study has been made possible only through the courtesy of the owners of the mine and of the general manager, Mr. G.

McM. Ross, whose thoughtfulness has been felt in every way possible.

HISTORY.

The mines at Copperopolis were first located in June, 1861, on what was called the Reed lode, after the principal discoverer. Over 11,000 feet of lode were located, and in the excitement which followed claims were taken up for twenty miles north and south. The Napoleon mine, the oldest copper mine in the state, and the Quail Hill mine are on a parallel lode six miles to the west; the Campo Seco and Lancha Plana mines are on a line about three miles west. This large copper belt in Calaveras County can be traced by stains and gossan for more than thirty miles.

Of all these mines, the Union and Keystone, at Copperopolis, were most productive in the early 60's, as they were also the most important in the state at that time. The oxidized ores extended only to a depth of twenty-five to thirty feet below the surface. The rich sulphides below were shipped to Swansea, by way of New York, to Boston, and to Baltimore. With the lowering of the price of copper in 1868 the mines were closed, and remained idle till 1887. A second period of activity followed, in which a hundred-ton Orford furnace was erected, and some high grade matte was produced. In 1892 a second shutdown occurred. The properties remained idle until 1901, when, under the present management, unwatering was begun. Up to, and including, 1866, the Union mine is credited with 56,500 tons of ore containing over 15 per cent. copper, and the Keystone with 5,719 tons. The copper produced was noted for its purity, ranking in the market with, or close to, Lake Superior metal.

At the present a large up-to-date plant has been partially completed. A hundred-ton oil-burning reverberatory furnace is producing from six to ten tons of high grade matte per day, only rich ore now being smelted. With the completion of the plant the production will be increased many times, and Copperopolis will again rank as one of the most important copper properties in the west.[1]

[1] References: Calif. State Mining Bureau. Eighth Annual Report, 1888, p. 150. Bull. 23, 1902, p. 23.

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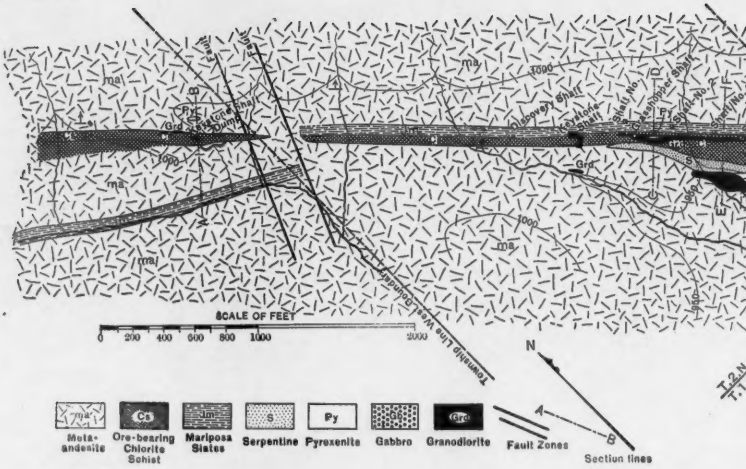
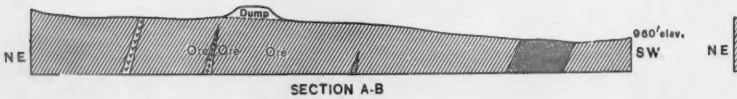
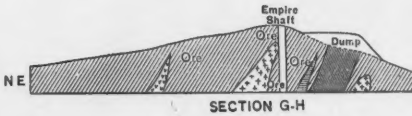
PLATE VII.



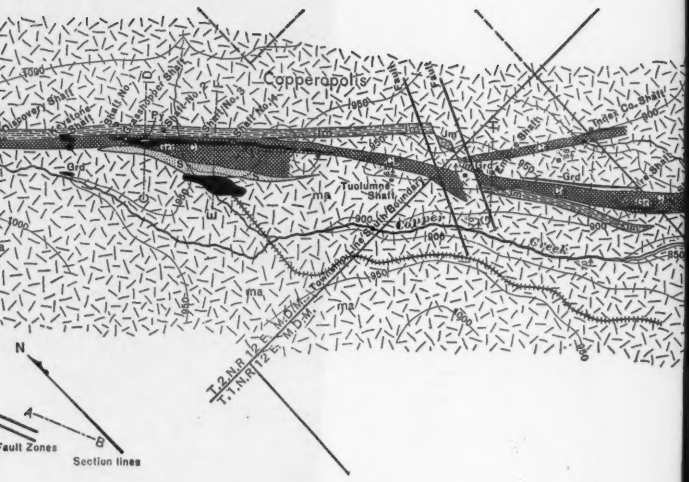


SECTION A-B



SECTION G-H

Scale of sections, 1 inch = 200 feet.



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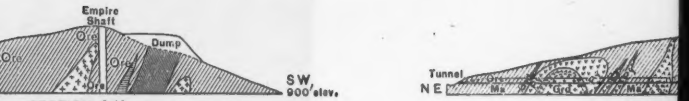
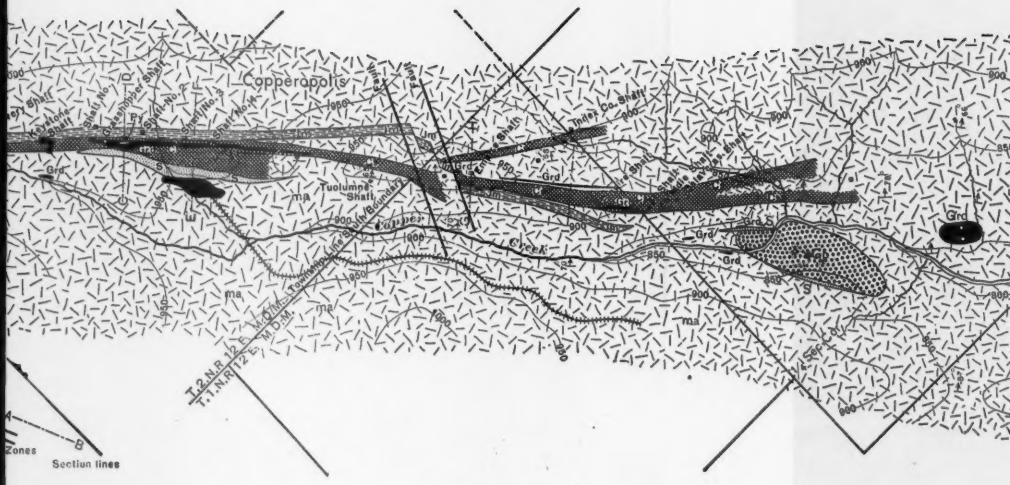


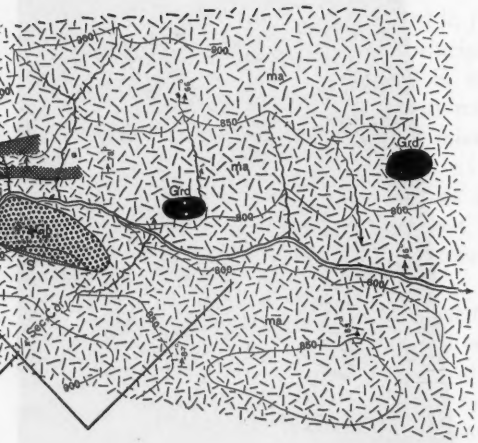
SECTION G-H

SECTION

GEOLOGIC MAP AND SECTIONS OF THE COPPEROPOLIS DISTRICT, CALIFORNIA. BY JO



OLOGIC MAP AND SECTIONS OF THE COPPEROPOLIS DISTRICT, CALIFORNIA. BY JOHN A. REID.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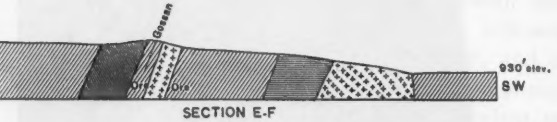
Gossan
930' elev.
SW

SECTION E-F

900' elev.
SW

Meta-andesite
Mariposa Slates
Serpen-tine
Serpen-tine
Grano-diorite
Contact Phase Grano-diorite
Pyroxenite

TOPOGRAPHY.

The region, although the elevation is not high nor the relief very great, has a well characterized topography, which is the result of the differential erosion of the various rocks. Two well-defined rocky ridges run northwest and southeast through the country: Gopher Ridge, four and one half miles west of Copperopolis, the first ridge east of the great valley; and the Bear Mountain Ridge, five and one half miles east of the town, separating the copper belt from the middle belt of the Mother Lode system. The lower ground between these two ridges is composed of a succession of short ridges often arranged *en echelon,* separated by long, narrow valleys. In one of these valleys lies Copperopolis, at an elevation above sea level of 980 feet. The ore itself is found to the north in the bottom of the valley; to the south, as the rock becomes more and more resistant to erosion, it occupies the center and sides of a low ridge. This ridge increases in size from its beginning near the center of the town (see section *E–F,* Plate VII.) to south of the concentrator, where it terminates, as shown in Plate VII.

The maximum relief is only a few hundred feet; the average is much less. (See Plate VII.) The elevations decrease progressively from the Bear Mountains on the east to Gopher Ridge on the west. The Jackson Folio shows well these salient features.

The streams of the region are divisible into the two types of the physiographers: consequent and subsequent. The Stanislaus river is the master stream of this immediate area, which, like all of the main rivers draining the west slope of the Sierra, is a consequent stream, with a course at right angles to the range crest.[1] These rivers, with local exceptions, flow over all rocks alike, and are responsible for the deep cañons of the range. The secondary stream courses follow in part the outcrops of the softer rocks, and in so far are subsequent; in part they also flow southwesterly across the strike of the country, through the lower passes between the overlapping ridges, and are consequent. The

[1] Jackson Folio No. 11, U. S. Geological Survey.

hot, dry summers usually cause all small creeks to become dry during this part of the year, but springs are fairly plentiful in the hills. The only source of water power is the Stanislaus river, which runs about six miles southeast of Copperopolis. Timber is fairly plentiful, the trees furnishing fuel being the common or digger pine, the live oak, blue oak, and some white oak. Travel to and from Copperopolis is entirely by team, the roads following the valleys wherever possible.

GENERAL GEOLOGY.

OUTLINE.

The general geology of the Sierra Nevada is well known. At the close of Jurassic time an immense thickness of sedimentary rocks, chiefly muds, sands, and gravels, together with interbedded volcanic tuffs and flows, were intricately folded into a mountain range, compressed and thoroughly metamorphosed into slates, schists, and allied rocks. The isoclinal folds of the range strike in the main parallel to the range crest, N. 40° W., and all dips, with only local variations, are about 70° E. The whole was intruded by vast masses of igneous rocks, the axis of the range being a great granitic batholith. Other igneous rocks were intruded after the initiation of the folding and compression, but before all such movements had ceased. Thus a great complex of rocks has been produced, and has been given the name of Bedrock Series or Complex. During Cretaceous time the range was eroded to a peneplain, a few monadnocks, such as Bear Mountain, remaining above the general level. During Tertiary time the streams cut to a second base level or peneplain, a little distance below the first, due to some slight elevation of the range. Near the close of the Tertiary, the whole range suffered differential elevation as a single great block; a great fault occurred on the eastern flank, and the old erosional surfaces were tilted gently to the west. The higher portions of the range were covered with lavas, and the old river channels filled by flows downward from the summit. Since then active erosion has gone on, carving the range into its present form. There are thus two

groups of rocks, separated by a great unconformity: pre-Cretaceous, composing the body of the range; and post-Cretaceous, or post-Jurassic, which overlie the first. The rocks of the first only, the slates, schists, and intruded plutonics, occur in the vicinity of Copperopolis; the gravels and lavas of the latter group are here lacking, though they occur but a few miles away to east and west.

ROCKS.

The rocks in the vicinity of Copperopolis, which all belong to the Bedrock Complex, are both of igneous and sedimentary origin, with a great preponderance of the igneous. Two divisions of these may be made: those which are largely metamorphic tuffs and breccias, represented by the meta-andesite and amphibolite schist formations; and the intrusive plutonics, represented by serpentine and talc, hornblendite, gabbro, and granodiorite. The pyroclastics are the older, and with the slates, the oldest rocks in the area; the plutonics are younger. The Mariposa slates occur as a thin tongue through the center of the Copperopolis region. Both ridges on east and west of the town are composed of the harder varieties of meta-andesites, with the softer rocks of the same formation, with the slate, underlying the valley between. Two miles to the north, where the two ridges approach closely, as shown in Plate VII., the amphibolite schist area wedges out in the schists of the meta-andesite formation.

A most important modification of the schists in this region is found in the large occurrence of chlorite schist, both microcrystalline and coarse-grained, through the center of the area.

The Jackson folio shows near the center of the south boundary line, the broader relations of the rocks around Copperopolis. The broad belt of amphibolite schist shown, however, wedges out rapidly just south of the sheet.

The rocks will first be described individually and then their inter-relations discussed.

Mariposa Slates.—The Mariposa slates occur here as a long, narrow tongue or wedge, which is about six miles in length. The northern end of this tongue is clearly shown in the Jackson

folio. The southern end is found just south of the town of Copperopolis, near the concentrator building of the mining company. With the exception of the three small breaks or faults on the mining ground, this slate area is continuous throughout. The most northern of these faults, which is about one half mile south of the Jackson area, cannot yet be conclusively proven to be a fault; it is inferred from those which are more clearly developed. If this be not a fault, the slate then occurs as two overlapping lenses of different lengths. In the copper area the slate lens is then usually less than one hundred feet thick, with a maximum thickness of one hundred and fifty feet.

In color the slates are a dark gray to black. They are finely fissile and homogeneous. Under the microscope the fissility is strikingly shown, the laminations being exceedingly thin. The rock is chiefly composed of isotropic kaolin, with a few very small grains of clear, low-polarizing silica. The rock is quite full of dark-colored dust, irresolvable by the highest powers of the microscope. Frequently small parallel veins of fine-grained silica cut horizontally across the slaty structure.

The amphibolite schists do not enter the immediate area of Copperopolis, as they wedge out about two miles north of the town. Detailed description therefore is not necessary. The Jackson and Mother Lode Special folios of the U. S. Geological Survey give all facts here necessary concerning them. The best exposures found just north of Copperopolis show a finely schistose greenish rock derived from a tuff. The strike and dip conform to the characteristics of the other formations.

Meta-andesite.—The formation of various rocks placed by Ransome under the one head of "meta-andesite" makes up by far the largest portion of the area. The topography is due, largely, though not entirely, to the differences in resistance to weathering among these rocks. There exists a gradation from the tuffaceous, clay-bearing, soft schists into the hard, massive, resistant augite porphyrites. Intercalated with these rocks, as an integral portion in the Copperopolis area, is a comparatively thin bed, or series of beds, of a basic chlorite schist. This

chlorite schist grades into the slates on the one hand and into the augite porphyrite tuffs on the other.

The harder rocks of this formation outcrop boldly on the higher ridges east and west, particularly to the east. The microscope shows the most massive rock to be an augite porphyrite, with augite phenocrysts in a groundmass of augite and feldspar. Much of the augite is altered to chlorite, especially the larger crystals. The feldspar in the slides examined is so far decomposed that identification is impossible. A small amount of clear, original quartz and some grains of magnetite are present. Not only does this massive phase of the meta-andesite occur on the higher ridges, but it is also found close to the chlorite schists in the valley at Copperopolis. One prominent outcrop is one hundred feet west of the new shaft, in the footwall of the ore. The rock here is fresher than the ridge outcrop and shows a finer grain and some clear feldspars. These feldspars show extinction angles of from 8° to 12° and belong to the oligoclase-andesines. This same facies of the augite porphyrite has been cut in the Index shaft near the outcrop. The porphyrite here shows less altered than the others and besides augite, which is all chloritized, and feldspar, considerable titanite and a little epidote appear. In the ninth level in the cross-cut east from the shaft to the main drift a small amount of the massive porphyrite occurs closely associated with the ore-bearing chlorite schist. Particular notice is made of this occurrence because of the relations of the decomposing augite and clear grains of titanite. The augite is largely decomposed. Clustered around many of these augites, as if derived from them, are irregular clear grains of titanite. The rock also contains some areas of quartz. The feldspars correspond to those of the other similar rocks.

The massive augite porphyrite grade into the tuffaceous facies through the more finely crystalline varieties. These tuffaceous rocks, the typical meta-andesites of the formation, are distinctly schistose, often finely so, and of a light, grayish-green when fresh. These rocks are best exposed underground in the east cross-cut on the seventh level. Such facies show broken crystals

of augite, feldspar and opaque dust, which is probably largely iron ore. In the tuffaceous meta-andesite in the ninth level crosscut, some traces of kaolin-like material occur, showing a transition to the clay slates. The transition is gradual, both microscopically (in the few slides examined) and macroscopically. In fact, the field transitions are strikingly apparent. The same holds true regarding the change from clay slate to chlorite schist. In the deep mine workings where the rocks are best exposed, it is often extremely difficult to distinguish the true clay rock from the slaty facies of the chlorite schist, and some specimens require the use of a microscope for identification. The tuffs, slates and the chlorite schists, in part at least, all seem to have been waterlaid, and this relation of clay rock and pyroclastic may be a common characteristic throughout the meta-andesite formation.[1] Also coarse breccias, amygdalytes and conglomerates occur in thin beds in different portions of the formation. One bed of coarse breccia is worthy of particular mention. This has a thickness of from four to six feet and outcrops continuously for a hundred feet or so southeast of the concentrator. The rock fragments embrace coarse and fine grained hornblende-bearing granitic rocks, sometimes gneissic, with andesites and other related rocks.

The chlorite schists are briefly described by their name, the typical rock being composed of chlorite alone or with very small and varying amounts of sphene, magnetite, ilmenite, apatite, quartz and epidote. The color is commonly a dark grayish-black, varying to almost a jet-black in the more crystalline facies. The finer-grained rock is slaty in structure, with quite perfect cleavage. Under the microscope it is seen to be cryptocrystalline, showing many small spherulites between crossed nicols. A dusty kaolin-like substance isotropic between crossed nicols is also present in small amount, and at times in the rock near the slate crystals of andalusite occur. The coarser varieties assume an ordinary schistose structure and become almost massive in the coarser-grained facies. The variation seems to be due entirely to the

[1] J. D. Whitney, "Geol. of Calif.," Vol. 1, p. 254. A. Knopf, "Notes on the Foothill Copper Belt of the Sierra Nevada," p. 418.

change in size of the chlorite crystals. The coarsest grained phase is found in the North Keystone ground on the dump. In this rock the chlorite appears in apparently well-defined crystals. In all the varieties the most constant accessories are sphene, usually in clear, rounded grains, and ilmenite in platy crystals. A few well-formed crystals of titanite were found but are rare. The ilmenite is frequently associated with its alteration product, leucoxene. In some few localities, notably at the small incline on the Empire hill and from the footwall cross-cut on the seventh level south, magnetite in very perfect, small, octahedra occurs. Apatite with the usual characteristics is seen in rare crystals. Some clear quartz in rounded grains, or aggregations of grains, occurs in every slide examined. Epidote is quite common in certain portions of the chlorite schist, but is not usually noticeable to the unaided eye. The schist was probably derived from a basic augitic tuff, closely related to the augite porphyrites. An analysis of a specimen of schist is given below. The titanium was evidently calculated as Al_2O_3.

SiO_2	36.30	FeO	17.52	MgO	3.40
Al_2O_3	32.09	CaO	2.00	FeS_2	1.02
		H_2O	6.85	$CuFeS_2$	trace
				Total	99.18

Serpentine.—The serpentine of the area occurs as a series of tongue-like intrusions all no doubt connected below the surface. A long, narrow area occurs to the north, on the area of the Jackson sheet, and it is the extension southward of this which forms the various occurrences at Copperopolis. Here it always lies to the west of the chlorite schist and ore. Its characteristics are the usual ones for serpentine in the foothills of the Sierra Nevada. Wherever exposed, the rock shows the effect of great lateral crushing. Under the microscope not sufficient structure remains to furnish exact data for determining the original constituents. Considerable calcite occurs in irregular areas and seams, and also numerous small crystals of iron ore. With the serpentine is always associated talc, usually schistose. The talc also occurs in separate dikes to the east of the serpentine areas.

Hornblendite.—The ultrabasic intrusives, other than serpen-

tine, while not rare in the older rocks of the Sierra Nevada, are yet in small amount. Hornblendite, as a distinct species, has received no notice in either the Jackson or Mother Lode folios, or in Turner's[1] papers upon the rocks of the Sierra Nevada. There is, however, considerable development of hornblendite at Copperopolis, though the actual outcrops are few and very insignificant. It is mapped under the ultrabasic family name of pyroxenite, as its affinity with this group needs emphasis, because of the rock relationships in the Sierra Nevada. This rock shows on the surface at but four points, only two large enough to map. These two exposures are near the North Keystone shaft, east of the ore body, and near the present working shaft, Union No. 1, west of the main ore outcrop. One small boulder-like occurrence exists to the north, just off the map, Plate VII., and the fourth is in the ravine east of the concentrator. Underground the conditions are different, and a large mass of hornblendite is cut in the Empire tunnel. (See section I–J, Pl. VII.) Small dikes of the rock are found also at different parts of the mine workings, as shown in sections 2 and 3. These small dikes show much squeezing, and it is frequently possible to pick out detached fragments from the schists.

In color the hornblendite is black when fresh, with at times a mottled appearance, due to small amounts of feldspar. In grain it varies from coarse, with crystals often one inch across, to porphyritic, with large idiomorphic hornblendes set in a finer hypidiomorphic granular mass of hornblende and feldspar. The latter is the most common type. The coarse-grained rock has no feldspar except in traces; the other variety has a small amount, usually less than 10 per cent. Under the microscope the hornblende is seen to be of the common variety, strongly pleochroic, and partly altered to chlorite. Many crystals of hornblende show veinlets of nearly colorless chlorite parallel to the cleavage, and the whole blotchy with secondary products. Some shreds of bio-

[1] H. W. Turner, "The Rocks of the Sierra Nevada," Fourteenth Annual Report, U. S. Geological Survey, Pt. 2, p. 441 et seq. "Further Contributions of the Rocks of the Sierra Nevada," Seventeenth Annual Report, U. S. Geological Survey, Pt. 1, p. 529 et seq.

tite are also present. The feldspars are much altered, frequently saussuritic. The extinction angles range from 19° to 21°, corresponding to labradorite. The only accessory minerals beside biotite are a few grains of titanite and chalcopyrite. The chalcopyrite is intergrown with the hornblende, and in the hand specimens grains can often be seen entirely within the boundaries of large unaltered hornblendes. This sulphide is not evenly distributed throughout the mass of the rock, but varies irregularly from none to 1 or 2 per cent. Further, the grains may be either irregularly distributed or arranged roughly parallel to veins of colorless amphibole.

Gabbro.—Gabbro occurs in only one location in the Copperopolis area, as a small boss near the south end of the ore ground now being developed. See Plate VII. The roughly circular outcrop is bordered east and west by serpentine, and north and south by a facies of granodiorite. The color is a greenish white. The grain of the mass is medium, but some of the rock broken for smelting purposes is coarsely crystalline, the individual crystals being from one half to three fourths of an inch in diameter. Diallage and feldspar in about equal amounts, with a little accessory pyrite, make up the entire rock. The diallage exhibits no characteristics out of the ordinary, and the feldspar is so badly altered that precise identification is not possible in the slides examined. Much secondary calcite is present in irregular areas. The old term of saussuritic gabbro seems quite appropriate until more detailed study can be made. The following partial analysis, made at the mine, indicates the composition of the rock.

SiO_2	45.50
Al_2O_3	20.58
FeO	3.52
CaO	12.44
MgO	10.12
FeS_2	1.11
Alkalies	not determined.
Total	93.27

The crystals exhibit some bending and fracturing, due to the strains to which the rock has been subjected.

Granodiorite.—The granodiorite outcrops in a series of irregular areas more or less parallel to the strike of the schists. These outcrops decrease in size from south to north, and eventually disappear. The most northerly exposure is near the North Keystone shaft. As with the hornblendite, much more of this intrusive is exposed in the mine workings, and no doubt can exist that the various exposures are all part of one large intrusion, whose top is exceedingly irregular. This top may be said to consist of a series of tongues extending upward approximately parallel to the foliation planes of the schists. A few of these tongues have been cut below ground. From all facts known concerning the granodiorite distribution, it is concluded that the main intrusive mass must be at considerable depth. The various sections and map show well the occurrence of this and other intrusive rocks.

On the surface the granodiorite is greatly altered; the fresh rock is developed only below the surface. The color is a light gray; and the grain medium fine. The texture is hypidiomorphic granular. The essential minerals are hornblende and biotite, now altered to chlorite, with both orthoclase and plagioclase and abundant quartz. The proportion of plagioclase to orthoclase is about as 2 is to 1, in the slides examined. The plagioclase is oligoclase, with extinction angles of about 9°. The chief accessories are sphene and pyrite. Some of the sphene and pyrite are associated with epidote, ilmenite and leucoxene, in chloritized hornblende, and may both be secondary in part. Other sections show both these minerals associated with clear original quartz and feldspar, and therefore original. The pyrite is in abundance. Strained and broken crystals show the effect of dynamic forces.

A different phase of the granodiorite is found on the Empire ground, both as outcrops and in the Empire tunnel. This is a white fine-grained rock, showing to the unaided eye glistening cleavage faces of feldspar and much pyrite in cubes. The microscope shows idiomorphic feldspar in a finer-grained mass of hypidiomorphic granular mass of feldspar and quartz. Quartz is not present in great amount. The orthoclase shows frequent Carlsbad twins; the plagioclase is identical with that in the

normal facies of the rock. Spots of chlorite represent the original ferromagnesian minerals. Pyrite is original, as in the common phase of the granodiorite.

Two other varieties of the granodiorite need mention. The small outcrop in the creek bed just west of the present working shaft, is a more acid facies. It shows chiefly orthoclase and quartz, with about one fourth plagioclase. Traces of biotite are present in shreds, with a very little chlorite and iron ore. The fourth facies is a basic modification which occurs in the Empire tunnel and elsewhere as a contact rock. The variation from normal in this appears to be in the greater amount of hornblende and the greater relative amount of orthoclase.

RELATIONS OF THE VARIOUS ROCKS.

Although all the details cannot yet be deciphered, yet sufficient evidence is available to establish some definite relationships of the various plutonic intrusives, and by inference, the relative ages of the rocks can be made out quite satisfactorily. It has been stated elsewhere,[1] by the geologists of the U. S. Geological Survey, that the amphibolite schists and the meta-andesites are contemporaneous in part with the Calaveras slates and in part with the Maripose slates. At Copperopolis, there is most frequently a gradual transition from the very slaty facies of the finer tuffs to the true clay slates, and the whole series seems to be of one age. Thin beds of pebbly conglomerate at times are found with the transition rocks between slates and schists. These rocks may then be regarded as the oldest of the area, into which the later plutonics have been intruded. The serpentine, probably an altered peridotite, was the first of these. Besides its dike-like character other evidence of its intrusive nature is found north of the area mapped, near the south line of the Jackson folio. Here the slate strikes a few degrees more northerly than the serpentine, with the result that the two rocks come into close contact. At the contact the serpentine has pressed up beneath the slate with such force that

[1] Mother Lode, Special Folio, U. S. Geological Survey, Jackson Folio, U. S. Geological Survey.

the slate is very strongly bowed, convex eastward. Also, the serpentine is in comparatively large amount at this joint.

Intruded into the serpentine at two different places are granodiorite and gabbro. The granodiorite-serpentine contact shows perfectly the relative ages of the two rocks. The former lies to the west, and near the latter becomes fine grained, due to rapid cooling. To the east of the contact plane is first a foot of talc schist, followed by one and one half feet of talc somewhat schistose, with the normal serpentine farther east.

The serpentine and gabbro are usually considered as about of the same age. However, the distribution of the two suggests strongly an intrusive character for the gabbro, and the surface cut turns this into certainty by exposing the chilled finer grained periphery of the gabbro in contact with schistose serpentine. It is probable, however, that the relative difference in age is not great, on account of the close petrographic relations of the two, and their invariable close association wherever found.

No contacts of normal granodiorite and gabbro could be established, but exposures of quartz-feldspar veins in silicified schist exist near the gabbro, cutting the gabbro-serpentine contact, and of later age. This quartzose material can be traced into normal granodiorite at other points.

The hornblendite has as yet been found actually cutting no rocks except the schists. It is intruded by granodiorite in a very fine exposure in the Empire tunnel.

On chemical and petrographic grounds it is likely that the basic rocks, serpentine, gabbro, and hornblendite, are relatively of about the same age. The serpentine is without doubt the oldest. Of the other two, the hornblendite shows greater effects due to dynamic forces and is taken to be the older. These relative ages will be assumed until further facts disprove them. There is, then, the following succession of intrusive plutonic rocks, beginning with the oldest:

1. Serpentine, from peridotite.
2. Hornblendite, as type of pyroxenite.
3. Gabbro.

4. Granodiorite.

Turner[1] gives as the succession of pre-tertiary igneous rocks of the Sierra Nevada, the following:

1. Intermediate, effusive,—greenstones and diabases.
2. Basic, intrusive,—serpentine and pyroxenite.
3. Acid, intrusive,—granodiorite.

This in keeping with the Copperopolis area, although no distinction is made between the various ultrabasic rocks.

STRUCTURAL MOVEMENTS.

Faults are not common on the west flanks of the Sierra Nevada, but the area under discussion shows a few which are well developed. Also, movements of a different character, small individually, but of the greatest importance collectively, are developed in the slates and schists, chiefly in the latter. Further, the movements producing schistosity in this region of weak rocks, have been long continued, as shown best by the ore. There are thus three distinct types of motion, and the results of each are vastly different. The largest movements are those of ordinary faulting, with a large horizontal displacement. The second type is shown best and perfectly in the ores, and consists of a vast number of reverse or thrust faults, each fault seldom having a throw of more than a few inches. The third type is that motion which has produced schistosity, and has resulted (1) by processes of dynamo-metamorphism, in the production of the slates and schists from ordinary sediments and volcanic extrusives; and (2) by long continued movement, in making the schists more schistose and the ore itself characterized by slickensided surfaces. More in detail, these are described as follows:

1. *Major Faults.*—There are three faults coming under the head of major faults, two of which are fairly well established and occur on the mining property. The third, or northerly, is yet problematical. The slate tongue described as occurring on the Jackson sheet comes to a sudden end about half a mile south of the end line of the mapped area, at the junction of the road

[1] H. W. Turner, "Age and Succession of the Igneous Rocks of the Sierra Nevada," *Jour. Geol.*, Vol. III., p. 414.

from Copperopolis to Milton with the road to San Andreas. The strike here does not change, but is a direct continuation of the tongue to the north. The meta-andesite bounds the slate on the south, as well as on the other sides. This point is on the east side of the valley. Proceeding on a line southwest across the valley, another outcrop of slate is found in the bed of the creek at the west side of the valley. This is just north of the limits of the map, Plate VII. This occurrence of slate can be traced by exposures in and near the creek to a point southwest of the North Keystone shaft, where it disappears. The strike of the slate is the usual one, except toward the north near the supposed fault, it bends gradually to the west. The facts upon which the inference of faulting are based are in the main two: (1) Demonstrable faulting of like throw further south; and (2) the topographic and geologic details at the line in question. The following generalized sketch map illustrates the topography and geology at this point. The rather heavy erosion of the small creek just east of the point where the slates disappear is very suggestive of a line of weakness due to motion in the rocks.

The second slate lens is continuous, as above noted, to a point southwest of the North Keystone shaft. Further south the slate is found displaced to the east, to the line of the outcrops of gossan and copper ore. The further facts tending to prove the existence of faulting here are: (1) A large number of individually small faults in the bed of a small stream here flowing westward across the formation, at right angles to the creek; (2) the presence of perennial springs along this line; (3) the displacement of the western ridge to the west, north of this line, with correlative broadening of the valley; and (4) the cutting of the creek across the western ridge of harder schists at this line instead of continuing to flow southward over the softer schists and slates.

Following this next slate area south, it is found outcropping on the line of the main mine workings as far as the concentrator building. Careful search, however, reveals the presence of a third fault just north of the Empire shaft. Here the fault is proved not only by the evident displacement, but also by a very

fine example of a slate friction breccia. This is best exposed in a surface cut a few feet north of the shaft. From this exposure the slate is followed to a point just beyond the south end of the precipitation boxes, in the creek. See Plate VII.

Small Faults.—The second type of rock movements is shown best in the ore and ore bearing schists on the lower mine levels. Small thrust faults, of little throw, dipping steeply both east and west, and rather flat lying, easterly-dipping thrusts shown in the ore seams, compose the visible effects of this motion.

Obviously, the cause of this structure might be pressure from either west, or east, or both. In the upper levels these pressure phenomena are less noticeable, increasing in size and number as greater depths are reached. The first impression received is that a horizontal force from the east has acted to produce the motion. Further search, however, makes it certain that the motive force has come from the west and below, the force due to the intrusion of granodiorite.

The movements producing schistosity belong to the greater orogenic movements which have resulted in the formation of the range. Therefore they need no further notice in this brief paper. The details which it is necessary to discuss will be taken up further in the second part dealing with the ores.

PART II.

ECONOMIC GEOLOGY.

ORES.

Nature and characteristics.—The ore of the Copperopolis belt is notable for its few minerals and its great purity of copper produced. This character is strikingly different from the other copper ores of the region. The ore at Campo Seco contains much zinc, with both gold and silver; the Poole mine, eight miles northeast of Copperopolis is somewhat similar to Campo Seco in minerals present, but contains galena in addition; the Napoleon mine eight miles west of Copperopolis, contains galena in addition to zinc, with some gold values and some copper ore

from near Hodson, two miles west of Copperopolis, is rich in zinc. The unaltered copper mineral in all the ores is chalcopyrite, which at Copperopolis is associated only with pyrite and contains no gold or silver values. Published accounts[1] of the various copper properties of the foothill copper belt give grounds for believing that the Copperopolis deposits are different, in age and conditions of deposition, from all the others.

At Copperopolis the ores are divisible into the two usual classes, surface, or oxidized, and deep, or unaltered. The surface zone of oxidized ore is very shallow, thirty feet or less, and a zone of secondary enrichment is entirely lacking. This is no doubt due to the fact that the intense lateral pressure in the rocks has prevented the formation of a vadose circulation. The actual surface is characterized by extensive gossan, in which occur seams of malachite, often very rich, coating the schist. A very small amount of azurite occurs, particularly toward the south. In the Empire ground, south to the concentrator, cuprite is found. Some very rich ore of this kind has been mined within a few feet of the concentrator, to the north. In a small incline shaft a few feet south of the Empire shaft, cuprite appears as small flakes in the gliding planes of serpentine and talc. The ground to the south, from the Empire shaft to the gabbro boss, shows the largest amount of oxidized ore, due to the greater shattering of the rocks by the latest igneous intrusives.

Beneath this oxidized zone occur the original sulphides: chalcopyrite and pyrite in a gangue of country rock, the latter being usually chlorite schist. The richest ore is pure chalcopyrite; the copper content is lowered both by admixture of pyrite and of country rock. The presence of too much schist or other rock makes a low grade concentrating ore; too much pyrite produces eventually waste material. Both the sulphide minerals, which occur relatively in all proportions, are found in thin veinlets or bands in the foliation planes of the schists, with a small amount in the gliding planes of the serpentine and talc. These

[1] Calif. State Mining Bureau, Bull. 23. A. Knopf, "Notes on the Foothill Copper Belt of the Sierra Nevada," Bull. Geol. Dept. Univ. Calif., No. 17, Vol. 4.

bands vary in thickness from one sixteenth of an inch or even less, to three or four inches. Rarely masses of chalcopyrite two or three feet thick are found, though the richer ore, consisting of a series of rather thin veinlets, is almost solid sulphide. In the richest ore, the individual bands of chalcopyrite do not always follow the planes of the schists, but form a reticulated mass seaming the rock in all directions. The appearance of such ore is much as if the original veinlets were in two series crossing at right angles, which were later squeezed into approximate parallelism.

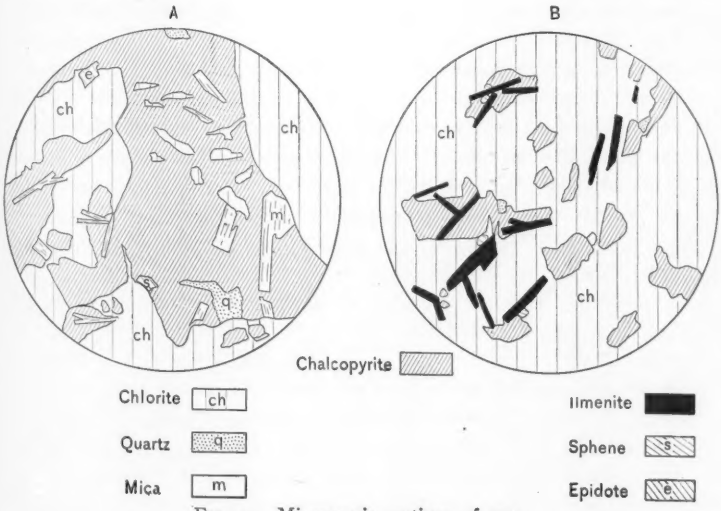

FIG. 42. Microscopic sections of ore.

Under the microscope the normal phase of the ore shows a few noteworthy characteristics. The sulphides are distinctly later than the chlorite, but are intimately associated with some of the other minerals present. Besides the chlorite, epidote, sphene, and ilmenite are present in small and varying amounts. In the interior of the ore seams the sulphides have no connection with any other minerals, but along the borders there is frequently an intimate association with ilmenite, sphene, and under some

conditions, epidote. The latter mineral is in part earlier than the ore and in part of the same age. The same holds true, in part, for the titanium minerals, though the ilmenite is almost always deposited with the sulphides. This association is probably due to the action of the original mineralizing solutions, which produced from the schists a portion of the epidote, sphene, and ilmenite, and dissolved and redeposited a large part of the remainder. The pyrite and chalcopyrite were deposited with these. The granodiorite has also had some effect upon the ore containing the epidote and titaniferous minerals. Some hematite has been produced from the ilmenite and all the minerals have been dissolved and reprecipitated with feldspar and quartz in addition. Some small amount of quartz, in microscopic grains, always accompanies the ore. In a few sections abundant plates of a micaceous mineral allied to muscovite are crystallized with the ore. Fig. 42 shows some of these characteristics.

Below is an analysis of a low grade, or concentrating, ore. No titaniferous mineral except traces of sphene are present.

ANALYSIS OF ORE.

SiO_2	21.14%
Al_2O_3	14.10
FeO	13.91
Fe_2O_3	11.51
CaO	.69
MgO	8.50
K_2O	trace
MnO	trace
P_2O_5	trace
H_2O	6.90
FeS_2	9.10
$CuFeS_2$	11.12
Total	96.97%

Paragenesis.—In age the two sulphides are the same, although some chalcopyrite is later than some pyrite, for the deposition was continuous during considerable rock movement. Typical thick veinlets of ore, consisting of both chalcopyrite and pyrite show the two minerals crystallized in a most intimate mixture, each on the other. Other specimens can be found which show heavy massive pyrite cut by veinlets of pure chalcopyrite. In

no case is the ore pyrite found later than the chalcopyrite. At times eyes of pyrite occur partially dissolved and surrounded by nearly pure chalcopyrite. See Fig. 43, *A*. The bearing of these facts upon the ore genesis will be discussed later. It is sufficiently accurate to state that, in the great mass of the ore, the two sulphides are of the same age.

Occurrences.—In describing the ore occurrences and the ore bearing zone, general characteristics will first be given, followed by detailed description of the separate portions of the productive ground. The rock which incloses the ore is a chlorite schist. This rock constitutes the sole gangue with a few exceptions to be noted later. It occurs both thinly fissile, when it has much the appearance of the clay slates, and massively schistose, when it has a very rough uneven fracture. The more massive variety contains the richest ore. The other gangue minerals are quartz, quartz containing recrystallized chlorite, and quartz-calcite, or quartz-feldspar veins. All this material is relatively in small amount, and is genetically connected with the granodiorite intrusions in different parts of the ore zone. A few thin seams of sulphides may penetrate the slates, but in no sense can this rock be regarded as ore bearing.

While it is true, speaking from an economic standpoint, that the ore has no well defined walls, it is also true that the ore bearing zone has rather definite limitations, particularly in the ground at present being exploited. The slate, wherever it occurs, has acted as an impenetrable wall to the mineral solutions, forming either a foot or a hanging wall of the ore. In like manner serpentine, or talc, at times has acted as a barrier to the mineral bearing currents.

In general, the richer ores follow the foliation planes of the coarser schist, approaching only to, or near, the tougher, more fissile, fine grained tuffs or clay slates and the dense serpentine. The granodiorite, because it is of later age than the ore, is of no importance in the present connection. The hornblendite, where it occurs within the ore zone, may be regarded, like the schist, as ore bearing.

It is necessary here to distinguish the surface ores of copper,

and similar appearing occurrences of pyrite without copper. The outcrop of the copper ore is marked by a heavy gossan, so that any heavy limonite deposits or stains in the immediate vicinity of the copper ground may be taken to indicate the presence of copper below. But heavy iron croppings do occur near the vein, which are entirely free from copper. The granodiorite has been described as frequently heavy with pyrite, and often dense, nearly solid masses of this mineral were found overlying this intrusive and genetically connected with it. Such pyrite is not cupriferous, and carries some values in gold. This is in striking contrast to the same mineral in the ore.

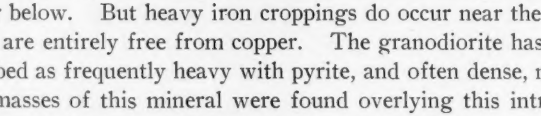

FIG. 43. *A*, pyrite inclosed in chalcopyrite; *B*, ore in schist.

For the sake of simplicity the ore bearing ground, at present only partly developed, will be divided into three parts, separated by the two faults discussed. See page 396. Beginning at the north, the first, or North Keystone section, lies north of the north fault; the second, or Union section, lies between the two faults; and the third, or Empire section, lies south of the south fault. In the second only has any deep underground examination been possible.

North Keystone Section.—In the North Keystone section the facts presented are based upon the surface geology, together with a few surface cuts, one short "grass-root" tunnel one hundred feet north of the North Keystone shaft, and the rather large dump at the shaft, which shaft is reported to be

about six hundred feet deep. Here the ore occurs in the most massive variety of the chlorite schists, and from what ore and waste are on the dump appears, on the average, to be the richest on the property. The arrangement of the rocks in this portion of the ore-bearing ground is largely inferred from occurrences southward. Serpentine, as is common, is on the foot, with hornblendite on the hanging. A small intrusion of granodiorite is present between these walls, outcropping as a thin dike in the tunnel one hundred feet north of the shaft. (See Pl. VII., section *A–B*.) The influence of the slate is problematical. The main belt is too far to the westward to have exercised much control over the circulating waters, but there are some tuffaceous beds nearer the shaft which have probably acted as impervious walls. From the North Keystone shaft northward, the strike of the schists bears westward into the hill on the west of the valley. The slate belt, from field study alone, appears slightly concave eastward opposite the shaft, but changes its course to more westerly toward the north, paralleling the schist strike. Owing to the intimate relations to the clay slates and finer tuffs, only a careful microscopical study will suffice definitely to locate the true slates. Further to the north, outside the limits of the map, the ore-bearing schists come into close proximity to the slates, and the hornblendite is only about one hundred feet east of the clay rocks. Hence, northward it is to be expected that the slates act as the footwall of the ore.

The rock present on the North Keystone dump shows that the ore seams are arranged not only parallel to the foliation planes but also cut across the schistosity, forming a reticulated mass of roughly rhombic form. The ore is more slickensided, showing evidence of considerable pressure and movement. The main distinctive characteristic of the ore in the first section is its arrangement into an anastomosing series of veinlets. This structure is due to the more massive character of the inclosing schist. which made it nearly as easy to be broken across the schistosity as parallel to it. Nothing can now be stated regarding the ore in place.

Union Section.—Shaft No. 1 is used as the working shaft and for detailed description the main interest centers here. The ore is not entirely confined to the chlorite schist, but is found also in some small amount as sulphide films in the gliding planes of the talc and serpentine. A similar occurrence will be noted for the Empire section, to the south. This ore in serpentine has not yet been sufficiently developed to become of economic importance, but should become of value in the future, for quite an amount of sulphides occurs in this manner. The walls of the ore zone are in the main well defined. This statement must not be taken to mean that all is ore between the walls of the ore-bearing ground. The clay slate is unequivocally the hanging wall of the ore in this section. Serpentine, when it occurs, as it usually does, forms the footwall, though commonly the workable ore fails to extend quite to this rock. A dike of talc, occurring a few feet east of the serpentine mass, often acts as the approximate footwall of the ore now mined. (See Fig. 44.) The

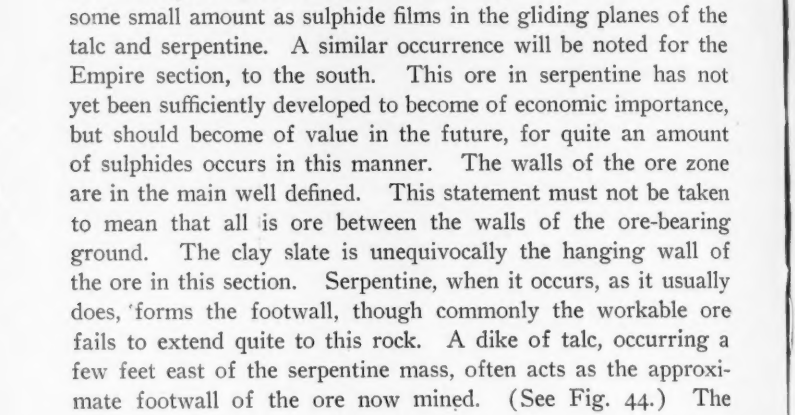

FIG. 44. Generalized section across ore on lower levels.

hornblendite is in the midst of the ore. The granodiorite is in no way connected genetically with the ore; to the south it often lies beneath the workable ore; to the north it is near the hanging wall slates; while in the center of the section ore occurs on both sides of and above it. Three sections show the ore zone and walls in cross-section; sections *C–D* and *E–F,* in Pl. VII., and Fig. 44, a generalized section in the lower mine workings. The more massive phases of the meta-andesite occur to east and west of the ore zone.

The influence of the various rocks upon the ore and the mine development forms a most interesting portion of the geology. Beginning with the oldest of the intrusive rocks, the serpentine, the effect of each upon the ore will be described. The serpentine is unquestionably older than the ore, for thin films and seams of chalcopyrite occur as coatings in the gliding planes of this rock. Only in a small portion of this intrusive does any ore occur, for the nature of the rock is such that mineralizing solutions cannot find ready circulation. The deposits of chalcopyrite and pyrite mark a peculiarly open portion of the mass. But there is no doubt that the serpentine and talc did act as the western wall of the ore solutions, and if ore is ever found west of the serpentine it will be because of an independent duplication of conditions.

The hornblendite at first appears to be a negligible factor. Where it is found in the underground workings it is associated

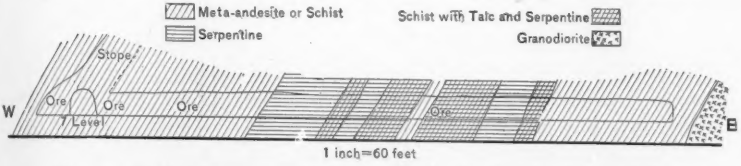

FIG. 45. Section in crosscut on level 7, south, showing ore in serpentine.

always with the ore-bearing schists and itself contains original grains of chalcopyrite. A few small squeezed and distorted dikes are to be located on careful search on the three lowest mine levels. All facts noted point to this intrusive as the one responsible, mainly at least, for the formation of the ore.

All the rocks thus far mentioned in this section, together with the slates, show evidences of much pressure and movement. All are likewise of earlier age than the ore, the hornblendite being in part also contemporaneous. The granodiorite, on the other hand, shows some, but comparatively little, evidence of the action of dynamic forces and is distinctly later in age. This rock as shown on the surface and developed under ground, exists as a series of tongue-like intrusions in, or bordering upon, the ore zone. Its presence here is no doubt due to the comparative weak-

ness of the mineralized belt. It has affected the ore both chemically and physically—in the first way, locally; in the second throughout large volumes. As is common with acid intrusions, it has not only intruded the schistose rocks but has also partly dissolved and recrystallized them along its periphery. The rock immediately in contact with the granodiorite and for a number of feet above the top of an instrusive tongue is invariably silicified and many small veins of white quartz seam the rock in the vicinity. The pegmatitic nature of such material is evident and its nature too well understood to require further comment. Where these quartzose veins cut ore, the quartz is often ore-bearing, where barren schist is cut, no sulphides are ever present. But the quartzose veins which traverse the ore are peculiar in that the sulphides in the quartz are on or near the schist walls and are not dispersed throughout. Where the ore in schist has been rendered quartzose, the sulphides show the dissolving and re-

FIG. 46. Section through top of granodiorite intrusion, level 7.

crystallizing effect of the superheated solutions and are evenly dispersed. The finest example of the action of the pegmatitic solutions on the ore comes from the Empire ground. The development of this siliceous ore is a factor of considerable economic importance as there is great need for such material in smelting.

Figure 46 shows the top of a single granodiorite tongue. Ore is plainly seen above the intrusive rock in the schist. This ore is all siliceous, for two or three feet above the granodiorite. Also, the outer portion of this rock is a contact phase, representing the product of the fusion into the schists of the intrusion, and contains some scattered chalcopyrite. The body of the normal rock is absolutely devoid of copper, as tested chemically at

the mine, but contains an abundance of pyrite. The physical effects of this intrusive are of great importance, particularly in winning the ore. The ore, the inclosing schists, and to some degree the slate hanging wall, all exhibit a vast number of faults, of two general series. One of these is made up of a small number of nearly vertical faults cutting across the ore formation at about right angles, and dipping either north or south. In the few faults of this kind examined, the throw was always such that the wall nearer the granodiorite moved out. More mine development is needed before these can be studied fully.

The other fault series consists of a vast number of small, nearly horizontal, displacements, striking approximately with the vein and dipping slightly to the east. These have been dismissed on a previous page; here it becomes necessary to describe their effect on the ore. In a small way this effect causes the ore seams to be displaced to the east on the lower side (see Fig. 43, *B*) and apparently has no great value practically. In a large way, the aggregate of all these individually small displacements has caused the ore to dip eastward much flatter than the dip of the planes of schistosity. Or in other words, the ore makes toward the hanging with depth. The faults show some evidence of increasing in size and throw with depth, as a few small lenses of ore have been cut off at their bottom and found some feet to the east going downward.

This faulted structure is characteristic chiefly of the ground now actively being mined. The ground both north and south fails to show this in so marked a degree, the reason being the larger development of the intrusive rock in the central portion. (See Plate VII.) And this maximum effect has been exerted differently in the schists and the clay slates. The chlorite schist is thoroughly faulted; the slate, on the other hand, has been bent rather than broken, though locally sharp-cut small faults do occur, of the same strike and dip as those in the other rocks. Also, the faults are shown by broken but straight laminæ. Thus the slate is slightly concave to the west, with a decreasing easterly dip. The change in dip, due to the series of small flat-lying

faults is due entirely to the granodiorite and in part to the earlier hornblendite. This curving of the slate was present in some part, at least, before the introduction of the ore, for the arrangement of ore lenses is connected genetically with this form of the clay rock. The clay slate itself has exerted an influence upon the ore in two ways. First, because of its impervious nature, the mineralizing solutions did not penetrate it and therefore it acts as the hanging wall of the ore zone. Second, because of its toughness, it acted somewhat as a restraining force against the opening of the schist zone just before the introduction of the ore, for the ore lenses are now found to feather out as the slate is approached.

The ore occurs as a series of overlapping lenses, often arranged *en echelon,* each lens being composed of a complex series of bands or veinlets of chalcopyrite and pyrite deposited mainly parallel to the foliation of the schist. These lenses or shoots pitch downward to the north as shown in section 11. These lenses are not separated by barren ground, but ore of poorer grades laps across from one to another. By poorer here is meant that ore poorer in quantity of sulphides; it must be kept in mind that the ore varies in copper content in two ways: change in amount of sulphides present in the schist and change in the relative amounts of chalcopyrite and pyrite. These ore lenses, or shoots, as they are termed locally, have a rather definite arrangement. The lens or shoot worked in the early days, known as shoot No. 1 (see Fig. 47), lies close beneath the slate from the present working shaft extending a few hundred feet each way in the lowest workings. Further north and south the ore becomes poorer until finally it is no longer sufficiently high grade to win. Northward the main drifts on each level are extended partly as crosscuts. At the end of the shoot No. 1 on each level the drifts bend sharply to the west, cutting across the strike of the rock and ore.

To the south the ground is not opened up, but from the southernmost drifts the slate hanging wall is seen to be bending to the southwest, in prolongation of the curve concave westward. This

fact by itself would indicate that the ore shoots in this direction overlap *en echelon* southwestward, similar to those to the north. However, the serpentine approaches nearer the slate in this portion of the ground, so that there can be but little, if any, overlapping of the lenses. The individual shoots are from thirty to sixty feet wide and several hundred feet in length, in a horizontal cross-section. More work of exploitation must be done before a more careful statement of size can be made.

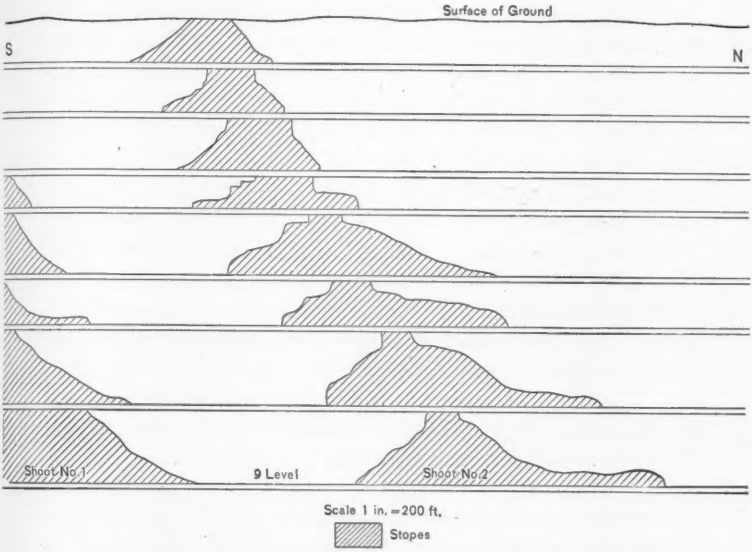

FIG. 47. Longitudinal section through ore bodies.

Empire Section.—In the third, or Empire section of the ore-bearing ground, no deep workings are now accessible, so that the geology of the depths is only to be inferred. The surface geology is given on the map, Plate VII., and sections *G–H* and *I–J* give the arrangements of rocks near the surface. The fault separating the middle and south sections is shown rather diagrammatically, as it is usually impossible to draw sharp contacts between slate and

schist. From this fault two ore shoots proceed southerly: one to the east of the low ridge marking the ore ground; and one to the west. The easterly one can be traced on the surface to a point southeast of the concentration, where some very rich ore, much like that in the North Keystone, was mined. The westerly shoot has the richest outcrop on the property, with an abundance of cuprite veinlets near, and just north of, the concentrator building. The serpentine, while not appearing on the surface in more than the smallest traces, is continuous underground, and very near, this west ore shoot. A comparatively large amount of both talc and serpentine cut in the one hundred-foot incline just south of the Empire shaft, contains sufficient copper mineral in thin seams to constitute a concentrating ore. Fifty feet north of the Empire shaft the granodiorite comes to the surface in a small knob a few feet across. The comparatively large size of this tongue is no doubt due to its location in the broken and faulted zone existing here. The north and south sides of this intrusion pitch steeply downward. The action of this rock is finely exhibited in many specimens, and much rich siliceous ore has been taken from the Empire shaft. The unaltered ore near the intrusion can be seen gradually to change from the normal, with veinlets of sulphides, interlaminated with the schist, into a quartzose mass containing irregular spots of finely crystalline, greenish-black chlorite, with very irregular masses of recrystallized chalcopyrite. Some of the quartz contains well formed crystals of calcite, of the same age. Feldspar occurs in the quartz veins only quite near the main masses of the granodiorite.

From surface outcrops and shallow cuts, it is very probable that a second tongue of granodiorite is present still further west, as shown in section *I–J*, Pl. VII. In this southern section there is a great development of the various intrusive rocks, which increase quite regularly in volume from north to south. On the surface of the Empire ground this is not altogether apparent, but the Empire tunnel shows clearly the under-surface relations. The position of the two ore shoots is indicated on both sections, *G–H* and *I–J*. The east shoot seems to be con-

tinuous from the shaft south to the creek south of the concentrator, and no doubt beyond; the west one is divisible into two. One of these is that developed by the Empire shaft; the other is to the south, exposed between the gabbro boss and the Empire tunnel, and outcropping best at the concentration. The tunnel cuts the north or upper portion of this south shoot. It is in this tunnel that the best specimens of hornblendite with chalcopyrite are found.

From the small granodiorite outcrop north of the Empire shaft two lines of intrusions radiate southward, approximately paralleling the ore shoots. The map and section *I–J* (Pl. VII.) show the relative positions of these. The face of the tunnel is almost to the westernmost, and the dome near the tunnel entrance marks the easterly. The one to the west can be followed by outcrops and in cuts to points on all sides of the gabbro boss and beyond. The east intrusion is the larger, and to the south half a mile exists in some large masses, forming low hills full of nearly horizontal quartz veins.

RELATION OF ORE MINERALS.

It has been stated on a previous page that the two minerals, pyrite and chalcopyrite, are in general of the same age, but that some pyrite is older than some chalcopyrite. The full explanation for this fact is found in a marked peculiarity of the ore which has not yet been mentioned. It has also been stated that the ore lenses feather out into barren rock. Not only do the two sulphides both decrease in amount toward the exterior of the lenses, but also the relative amount of pyrite becomes greater from center to outside, eventually to the complete exclusion of the chalcopyrite. These facts hold true on all sides of an ore lens. Thus, an ore lens, in horizontal cross-section, is an elliptical mass, with rich chalcopyrite in the center and pyrite on the outside, with a zone of transition between. Careful examination reveals further that the change from chalcopyrite to pyrite is attendant upon the closing of the openings in the schist to mineralizing solutions. Where fissures are open, as in the inside of the lenses, there is nearly pure chalcopyrite; toward the peri-

phery the fissures are less open and more pyrite is present; on the outside no openings are present which connect inside and outside, and pyrite only occurs. Further, when a single small fissure in the schist, containing chalcopyrite, becomes closed temporarily by a film of chlorite, the same fissure continued on in the rock contains only pyrite. Or, as is often seen, small openings closed at both ends, close and parallel to a larger opening

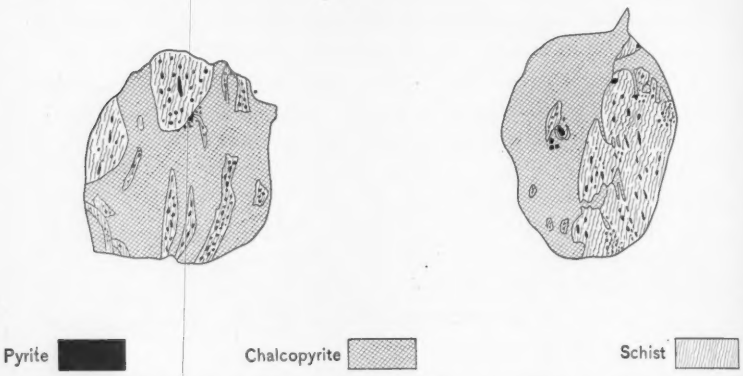

FIG. 48. Sections of ore showing relations of sulphides to schist.

containing chalcopyrite, is filled only with pyrite. Figure 48 shows such ore.

The ore may be divided into three quite distinct grades, varying as indicated. These are:

1. Veinlets of nearly pure chalcopyrite, in fully open fissures, with clear cut walls. A very small amount of pyrite is very intimately associated with the chalcopyrite, and visible only under a microscope.

2. Veinlets of chalcopyrite and pyrite intimately mixed; pyrite either fine or coarse; vein walls less perfect than in class 1; in less open fissures; and commonly separated from class 1 by a shattered wall of schist. Where pyrite is fine-grained the fissure has better walls and is more open to the man fissures. When pyrite is coarser it is due either to (*a*), less open fissures, or

(*b*), a later deposit of chalcopyrite around pyrite, or (*c*) a small film of chlorite on one or all sides.

3. Veinlets of pyrite, regular or irregular, separated from classes 1 and 2, by schist films and walls. Chalcopyrite, when it occurs with these veinlets, is always later in age, and either is in the pyrite in small veinlets recognizable only under the microscope, or as solid masses surrounding kernels of pyrite. Rarely, a specimen shows that the pyrite-bearing fissure has been opened to the rich copper solutions and the pyrite partially dissolved. See Fig. 43, *A*.

A subclass under class 3 might be made, to consist of the pyrite-bearing schist outside the ore lenses. Such pyrite is composed of cubes and pyritohedrons at times one half an inch in diameter, and occurs in the rock near the ore shoots. Such material, in mode of formation, is in no wise different from pyrite-bearing slates and schists forming the walls of the gold veins of the Mother Lode.

There is a fourth variety of ore, which might be placed in a subclass in a scheme of classification. This is the quartzose ore connected with the granodiorite intrusions, and is the only ore in which free silica can be seen by the unaided eye.

From all these facts concerning the ore, but one mode of formation is deducible. Both macroscopic and microscopic evidence point to the different osmotic pressures of the two sulphides in solution, exerted throughout a rather prolonged period of ore deposition, as the true cause. This is in keeping with many facts elsewhere observed. The presence of cubes of pyrite in apparently impervious rocks near ore deposits, the growth of which has displaced the rock itself, is very common, and in the clay gouges of vein walls cubes of pyrite can frequently be found forming at present, as on the Comstock. It seems hard to escape the conclusion that the iron in certain solutions has a great osmotic pressure sufficient to carry it away from other minerals, including gold. For in so many mineral deposits the vein and wall rock both carry pyrite of the same age, with the vein pyrite rich in gold and the wall pyrite very lean or barren. Some of

such wall pyrite is due to the action of waters containing sulphides upon iron-bearing minerals, but much more is clearly not thus formed. Certain rocks at times appear to act as septa, impervious to some mineral substances and pervious to others. In the chlorite schists at Copperopolis the chlorite has acted as the septum, impervious to the copper in solution, but permeable by the iron.

Few references have been made by geologists to osmotic action in mineral deposits; it would appear that here is a promising field for investigation, particularly in a laboratory way. Becker[1] and Lindgren[2] have noted some suggestive occurrences, the former being the first to suggest the application of osmotic action to ore deposits.

GENESIS OF THE ORE.

The ore is peculiar in its small content of minerals present beside the chalcopyrite and pyrite. The small amount of silica is the only one which was deposited with the sulphides, and some of this may be original in the schist. The ilmenite and sphene associated with the ore have probably resulted from the alteration of titaniferous pyroxene, similar to that change of the augite in the augite porphyrite. The waters carrying the ore were probably essentially alkaline sulphide solutions carrying copper and iron with small amount of silica. Solutions of such simple character were rather rare in this portion of the Sierra Nevada.

The source of the solutions and their copper content is connected with the hornblendite. This rock contains original chalcopyrite, and is always found with the ore in the chlorite schists. Two samples of the sulphide-bearing hornblendite were treated chemically, and the sulphide determined to be pure, or nearly pure, chalcopyrite. The granodiorite, containing original pyrite, was tested from a number of localities, but was unvarying in its freedom from the merest traces of copper. The conclusion is

[1] G. F. Becker, "Quicksilver Ore Deposits." "Min. Res. of U. S.," 1892, p. 21; "The Gold Fields of Southern Alaska," Eighteenth Annual Report U. S. Geological Survey, Pt. III., p. 68.

[2] W. Lindgren, "Gold Quartz Veins of Nevada City and Grass Valley," Seventeenth Annual Report U. S. Geological Survey, Pt. II., p. 183.

drawn, therefore, that the earlier hornblendite has been responsible for the copper-bearing solutions, the magma from which the hornblendite came furnishing the copper. The gold-bearing non-cupriferous pyrite was derived from the acidic magma of the granodiorite.

In age the ore is earlier than the gold-bearing veins of the Mother Lode region. These veins are associated with the acidic intrusives of this part of the Sierra Nevada, which are distinctly later than the copper ore. Quartz veins of the Mother Lode type, with auriferous pyrite and free gold, occur in the Copperopolis region, some of which, at least, are associated with the granodiorite intrusions, and connected genetically with them. The series of basic intrusives, represented at Copperopolis by the hornblendite, is in all cases earlier than the acid rocks. The Copperopolis deposits are to be listed among the oldest ores of the Sierra Nevada.

FUTURE IN DEPTH.

As a matter both of scientific and mining interest, the question of the permanence of ore with depth needs mention. There are a number of facts throwing some light upon this.

1. The ore occurs in veinlets, in the main interlaminated with the schists. These schists, from all mining work done in the great Sierra belt, and the deep cañons of the range, go downward unchanged to great depths.

2. The hornblendite, the source of the ore, undoubtedly extends downward in the form of thin intrusions to great depths.

3. The granodiorite, which is responsible for many quartz veins containing pyrite and gold, which veins lie *above* the intrusive rock, is later than the copper ore.

4. All mining developments throughout this country have always shown that ore values are present downward to the greatest depths reached.

5. Lastly, the ore at Copperopolis not only proceeds downward as far as exposed with undiminished values, but is slowly increasing in richness and volume.

Therefore, there can be but little doubt that the Copperopolis ores reach downward at least for several thousand feet.

RELATIONS OF THE COPPEROPOLIS REGION TO THE MOTHER LODE.

The ore deposit at Copperopolis has been described as lying between the middle and west belts of the Mother Lode system. The truth of this statement is everywhere forced upon the observer in the country surrounding the copper deposits. Typical mariposite is found near Hodson, less than two miles to the west, in the vein formation at that point. Dikes of quartz and feldspar, so common along the middle belt of the Mother Lode, as noted by Ransome, are to be found in the slates west, north, and south of Copperopolis. Quartz veins with carbonates exist a few miles to the south. And on the Empire ground, as noted, some of the quartz veins above the granodiorite contain original calcite, showing the Mother Lode characteristics later than, and imposed upon, the copper deposits.

The Copperopolis ores are to be regarded as an early non-auriferous deposit in the great meta-andesite formation of the western Sierra Nevada, which has been surrounded and intruded by later gold ores of the Mother Lode type.

SUMMARY

The Copperopolis copper deposits may be finally described as consisting of a series of ore lenses of unknown depth, in part arranged *en echelon,* and in part serially along one line. In horizontal cross-section these lenses are from thirty to sixty feet wide and several hundred feet in length, with rich ore in the center changing into low grade pyrite at the periphyry. This change in the copper content of the ore appears to be due to the action of the chlorite schist as a septum, impervious to the copper, but permeable by the iron in solution. In the body of the ore lenses the value changes by the varying amounts of schist with the sulphides; from inside to outside the values change by the increase of the relative amount of pyrite. Chalcopyrite is the only copper ore in the unaltered zone, and is associated with but

one other sulphide, pyrite. No gold or silver are present. A second variety of pyrite, containing some gold values, frequently occurs with the copper ore. This pyrite is genetically connected with the latest intrusive rock, granodiorite. The gold veins of the western portion of the Sierra Nevada are connected with the series of acid intrusive rocks, which are of later age than the group of peridotites, or the ultrabasic intrusives. The copper ore is connected genetically with a hornblendite, an ultrabasic rock, and therefore is older than the gold-bearing quartz veins of the Mother Lode. The copper ore is of special scientific interest on account of its genetic relations and mode of formation. From all indications, together with the large amount of ore in sight in the workings, Copperopolis bids fair to become one of the largest copper producers in the west.

DISCUSSION

This department has been established by the editors in order to afford to those interested in questions relating to economic geology an opportunity for informal discussion. Contributions are cordially invited either in the form of discussion of papers appearing in earlier numbers or bearing upon matters not previously treated. Letters should be directed to the Editor, South Bethlehem, Penna. The full name of the author should be attached to all communications.

THE TRAINING OF ECONOMIC GEOLOGISTS AND THE TEACHING OF ECONOMIC GEOLOGY.

Sir: The subject of the proper training of economic geologists and the teaching of applied or economic geology is receiving much attention from geologists and teachers. Recent discussions have occurred, the results of which can be applied to all higher education of the present day. It appears to the writer that more stress is needed upon the fundamental principles involved.

Of what must the education of the economic geologist consist, and what should be the order of presentation of the various parts of this education? This is the question in its broadest form. We aim to produce, as a result of such education, men of greatest value to themselves and the country. It must always be kept in mind that all men differ mentally, and that any proper plan of education must get the best results from each student.

It is necessary here to define a few important terms. First are the related ones: *theoretical* and *practical.* Both have acquired an unfortunate connotation, the effect of which has been a decided haziness in their use. *Theoretical* knowledge or training is that which deals only with principles and their derivation. The common derogatory meaning is well known. *Practical* means, best and properly, the application of theory to practice, of doing the world's work by using correct principles in the right manner. The further meaning of this word, now

sanctioned by the best authorities has resulted in much confusion in our thinking. To be truly practical, a man must be able not only to do work, but must know why that work is done, and be able properly to improve both method and means when possible.

Second, are the terms *science* and *applied science*. By science we mean that body of knowledge classified, co-ordinated and systematized into one complete whole. Applied science is *not* the application of a science as a whole; it *is* the application of certain principles *only*, chosen from out a science. To be used to best advantage, the *whole* of a science must be drawn upon in many *indirect* ways. This is too frequently overlooked. As an example, and in other words, applied geology, *at any one time*, is composed of a particular category of geologic principles used to solve problems of direct utility, which principles increase in number as the problems become more numerous and complex.

Next, considering means of education, something definite must be meant by the terms, *university* and *technical school*. These two are different in aims and methods, and should not be confused. A university aims primarily at good citizenship, in its fullest significance. A technical school aims to fit men for the engineering professions. The difference is evident; there is a likeness as well, for both aim to produce men who shall work for the best interests of their country. For this latter result, however, at least a partial broad university course is necessary.

Lastly are the related terms, *scientific education* and *technical education*. The one obviously stands for a training in science as science; the other stands for that training which cultivates the power to apply science to material problems. A technical education, to be truly scientific, which it often is not, must have a complete foundation of pure science. Shortcut methods, which are all too frequently used, are based on the erroneous idea that applied science is made up for all time of only a set aggregation of principles to be used in work.

From this it follows that there are three more or less distinct kinds of education based primarily upon science: the purely sci-

entific; the scientific-technical; and the non-scientific-technical. Each of these produces in general three well-defined classes of workers. The first gives us the men of pure science, whose lives are spent in establishing nature's laws. The universities produce these men. The second gives the world the men who not only apply science but also are keen in necessary practical research. The universities and best technical schools produce these practical scientists. The third furnishes us those men who are able only to apply certain portions of science, and have little or no ability to do more than this. Shortcut educational methods in the poorer schools are responsible for this class of mechanical workers. The first two are truly scientific; the third is not so.

Thus we have three classes of workers, whose labors depend fundamentally upon science, and we must examine the kinds of instruction producing each. But, as we are considering scientists only, and economic geologists in particular, the third class drops from our attention. The question resolves itself into this: What sort of education is necessary for pure scientists and what for applied scientists? or, bearing particularly upon our main theme, what is proper, in substance and methods, for a practical, or applied, geologist?

The education of scientific workers is divisible into two distinct parts: an earlier, or preliminary, and a later, or finishing, part. These two parts must be kept absolutely separate for the best results. Of the two, the first is obviously the more vital, and as each decade passes, is required to be more and more thorough. The world is constantly asking for men with broader and more comprehensive learning, as well as special knowledge, yet many of our educators and educational institutions remain deaf to the call. Of these parts of a scientific education, the first, or earlier, embraces the study of the pure sciences, together with all the other subjects necessary both for use in later scientific work and for their broadening influences on the mind. All these may be listed under three heads: (1) Those of elementary scientific nature, dealing with the fundamentals of science; (2) those not in themselves scientific, yet necessary for scientific work; and

(3) the humanistic studies, without which no man's work can be of the first magnitude. For an economic geologist, mathematics, physics, chemistry, biology, elementary mineralogy and elementary geology represent the studies of the first class; English, French, German, economics, and law indicate the nature of the second; history, literature and elementary sociology stand for the third. It is beyond question that both classes of scientists should have the same earlier education. The final part needs careful treatment, for herein lies the present confusion in regard to technical training. It is commonly held that, as soon as the embryo applied scientist has been equipped with a knowledge of the fundamentals of science, he should immediately begin his final studies of applied science. This belief is not correct. For a man to become an applied scientist in the best sense he cannot step directly from elementary science into applied science; he must be trained in the complete subject, with methods of research, with no particular stress laid upon economic problems, and must be as ready as the pure scientist to attack new problems. The reasons are plain: (1) Elementary science is by its nature an incomplete subject; (2) by a study of applied science alone a few principles *only* are well illustrated by the usual type cases; (3) purely scientific problems are best fitted to develop *all* sides of a science, to cultivate the use of the many principles, and to develop the fullest mental powers. If an economic geologist does not know all the principles which bear on his problem, or fails to understand their inter-relations, his work is sure to be in error. No shortcuts to mental power and equipment are possible, and yet the old cry for things "practical" is forever heard. A student remarked to the writer not long ago: "I like economic geology, but I don't like dynamic and structural geology; why does a fellow who expects to mine need to take anything but economic?" Comment is unnecessary.

Of the education of the two classes of scientists, the first parts are the same, the second differ in that the pure scientist is trained chiefly along the lines of pure science, while the applied scientist is trained both in this wise and also along lines of practical

research. Further, a humanistic standpoint on the part of the teacher should at all times be occupied. There is too frequently, on the part of our instructors, far too little knowledge of, and sympathy with, the work-a-day world. Lastly, in regard to the economic geologist, the later specialized part of his education should embrace portions of such practical science as metallurgy, mining engineering and civil engineering.

Following this outline of the studies embraced in the education of an economic geologist, come the methods of teaching pure science and applied science. There are three distinct ways of imparting scientific knowledge, each for a different purpose. These three may be first divided into two: (1) juvenile, and (2) adult. The latter is divisible into: (*a*) quasi-scientific, or "practical" scientific, "practical" here being used in the common narrow sense; and (*b*) the truly scientific, or logical scientific. Essentially, the juvenile method consists in presenting science by means of its applications to every-day life, for youthful minds cannot grasp abstract principles. It would be entirely unnecessary to mention this method were it not for the fact that it is too frequently used for the grown-ups, who are capable and ready for something more advanced. If a student preparing for economic geology cannot readily grasp, and mentally assimilate, the various geologic principles, but must have such principles fixed in his mind by numerous citations from engineering practice, that student is in no way fitted to enter upon the formal preparation for his chosen field of labor.

Of the adult training, the first kind, or so-called "practical" method, many times savors strongly of the juvenile. This sort of education consists merely in giving a student just those principles which can be used immediately in the solution of practical problems, as illustrated by actual cases from the work of the world; the rest of the science is cast aside as of no value. The result is inevitable; the men produced are nothing more than mechanical workers. It is unfair to call these men scientists or fully equipped engineers, for to be such, men must have at their command *all* the principles of science to aid them in time of diffi-

culty. This is not an overdrawn statement. One main resaon why we have so many third rate engineers, and so few first rate, lies in the fact that so few have a full knowledge of pure science. Further, in this kind of instruction, in which the stress is laid upon the applications of principles almost before the principles are enunciated, little or no training can be given in the inductive or scientific method of reasoning and research. A student who is concerned chiefly with practical applications of principles has no patience to spend time on seemingly useless work.

The last method of teaching science, the proper way, is essentially the presentation of observed facts in logical order, or, in laboratory practice, by the students first observing and later arranging logically the many facts of a subject, and then from these formulating the principles of the complete science. Not only is there gained an intimate knowledge of all the principles, but also the requisite training for the attack and solution of new and unfamiliar problems. It is essential, very apparently, that the students shall have reached the age at which logical processes and inductive reasoning can be used and enjoyed. The application of principles as a study must come only after this first work has been accomplished, else the student scorns the analytical training and more complete knowledge. It is not meant that principles should not be illustrated. Far from it. The more illustrations the better, within reasonable number. A great stumbling block lies right here, an unconformity in thought, to borrow a geological term. It is this: The illustration of *a principle* and the illustration of *the practical application of a principle* are two very different things. It is one thing to illustrate simple folding by the classic example of the Jura Mountain, or by the asymmetric Appalachian folds; it is a vastly different matter to use as an example to illustrate the same, cases of folding in oil-bearing regions, where the anticlines are noted for oil wells and the synclines for no value. In the one the attention is directed wholly upon folding as such; in the other, the thought is focused on the use of a fold in finding oil. If a science is a group or system of correlated principles, it follows that to grasp a science

one must not only understand each of the component principles, but must also comprehend their complete co-ordination. Hence, if a student's mind be filled with the principles of a science, some of which have been illustrated by their practical bearings on the world's work, and some by pure examples, but a partial co-ordination can at best be made, and the unity of the whole is forever lost. There is no gainsaying the statement that principles must be thoroughly inculcated if a student is to obtain the proper results of his study, but it should be understood that all the principles must be equally well presented and equally well absorbed in order that they may be fused into a unified science. The question resolves itself into the proper mode of presentation. Given: to furnish students with a complete working knowledge of a science, what method of instruction should be used? In geology, to turn out an economic geologist or engineer, the interrogation not infrequently takes the concrete form: shall the principles of dynamic, structural, and historical geology be taught by illustrating with examples from engineering practice; or, in the extreme form, shall pure geology and economic geology be given together? Keeping in mind that a full scientific knowledge is to be gained, there is but one answer. The interest of the students is held, not by science, but by science as a set of mechanical methods or procedure for working out problems, and they unfailingly grow impatient of those parts which seem to them not connected with their future work, and slight everything deemed by them "not practical." It will be granted that applied geology and pure geology can be given together, but only under two vital conditions: (1) An experienced, keen, sympathetic teacher; and (2) students who have a fund of worldly experience and preparatory training sufficient to give them a true insight into the ultimate nature of their studies. Such a combination does not exist among the undergraduates of our universities and technical schools, and is therefore beyond the limits of this discussion. Moreover, although such instruction may be possible, it can never in all respects be the best, for reasons already given.

But though we have thus far discussed the matter within the

usual limits, there remain other and vital phases of the subject. What has already been said has come from one viewpoint only; there is another standpoint from which we must proceed anew. The world needs men not only of knowledge and power sufficient to harness nature to our needs, but also of such intellectual caliber that they can seize upon and shape to highest ends, the onward march of civilization. Let it be stated broadly and simply: The engineers and practical scientists of to-day, to be of the greatest possible good to the world and to themselves, must be not only practical scientists, but also practical idealists. To deny this is to acknowledge one's blindness to the needs of the world. We need men of ideals, men who can see beyond into the future, and who have the requisite powers to apply these ideals to every-day existence. Science, properly taught, produces such men; improperly taught, it fails utterly to differentiate its votaries from the common level.

In the abstract, science, as a formal study or recreation, has a dual aim: *material* and *spiritual*. The first, or material, has already been treated; the second must be examined in a complete discussion of the main theme. The world-old and yet unanswered question, "What is the meaning of life," can be asked no longer only by each individual of himself, as a possible help to *individual* work and happiness. It must be asked, and partially answered, by each worker in the world, with reference to the influence of his labors upon his countrymen. The world is requiring this in greater and greater degree, and we, as world workers, can do this only by being developed both from the material and the spiritual standpoints; we must be both practical scientists and practical idealists. The question then takes this form: How must a scientific education be given in order that men with clear cut notions of utility and of ideals be developed? A little consideration should make the answer plain. A proper study of science, as a co-ordinated system of laws, does that which no other study can do; it gives us a rational basis for spiritual belief in the unity of the universe; it makes life mean more and more to us; it gives us both energy and ability to become truly

the world's workers and leaders. If men study science by prostituting it into a mere means to a narrow end, they work always in a mist; life means to them the making of a livelihood, nothing more, and the final result of their labors is comparatively little. Geology, because it is one of the most catholic of the sciences, is perfectly fitted to develop the ideal. After a proper study of geology, the world and life begin to assume coherent form, and thereafter all knowledge becomes, as it should become, a source of light upon the question of life's destiny. It is not meant that this is the only, or best, way to reach ideal conceptions; it is to be remembered that the education of a geologist is under our microscope. If, then, with such a basis, not alone of geology, but of the other sciences as well, a student enter upon the study of applied geology, his grasp of the problems which confront him is rendered exceedingly firm, so that the grade of his results reaches the highest possible point. This is impossible from either standpoint if pure science and applied science become indiscriminately mixed in their presentation.

But, let it be reiterated, the ideal point of view requires for its inception not alone a thorough study of pure science combined with a study of the humanities, for beyond this the instructors must present the technics of engineering or applied science from the truly human standpoint. One of the greatest criticisms, if not *the* greatest criticism, of higher education to-day, is that college graduates disappear from sight after leaving their Alma Mater; their citizenship is of low order. The criticism is a just one, and the reason is to be found in the preceding; our educators fail to impress upon their students the vital fact that the intellectual man must lead not only in lines of commercialism or business, in professional life, or any sphere of human activity, but must lead as well in the social upbuilding of the nation and the world. We need more engineers like William Barclay Parsons; we need more laywers like William Travers Jerome; we need more statesmen like Theodore Roosevelt.

Therefore, our educational institutions, whether they be universities, colleges, or technical schools, must aim to turn out

men who shall be not only well grounded in all that pertains to actual work in their chosen professions, but shall also be good citizens, both of their own country and of the larger world. If men of this stamp be not forthcoming, our system of education needs radical revision, for the constant demand of the world must be met.

JOHN A. REID.

STOCKTON, CAL.

THE GENESIS OF THE LEAD AND ZINC ORES OF THE MISSISSIPPI VALLEY.

Sir:—As a result of investigations carried on in the Joplin district, especially in the Aurora area, in 1902, I was convinced that Dr. Bain in his report on "The Lead and Zinc Deposits of the Ozark Region" had mistaken, in many places, the unconformity between the Mississippian and Pennsylvanian series for faulting, because of slickensides developed as a result of settling of the shale beds and discordance in bedding between members of the two series. His attention was called to this fact, but he believed that the faults were present and could be found upon sufficient study. Later I had occasion to examine certain areas in the vicinity of Joplin, where faults had been mapped by Dr. Bain, but I was again unable to find them. The Pennsylvanian shale is everywhere more or less slickensided as a result of movements due to settling and the Mississippian limestone is also occasionally more or less smoothed and striated, but these are not in themselves evidences of movements having the magnitude of the faults mapped by Dr. Bain.

Again I called attention to the fact that the fault breccias—so-called by Bain in his report above referred to—were due chiefly to solution and not to mechanical stresses as Bain had supposed. This was pointed out by Arthur Winslow in his report on the "Lead and Zinc Deposits of Missouri," being simply confirmed by my observations.

Shortly after the publication of Bain's report on "The Lead and Zinc Deposits of the Ozark Region," W. S. Tangier Smith and Dr. Siebenthal began a detailed study of the area included

within the special Joplin topographic sheet. During the progress of this work, I visited the area with Dr. Bailey Willis, pointing out to both Mr. Siebenthal and Mr. Willis the error which had been made by Dr. Bain in mapping unconformity as faulting. I recall one instance in particular where this was exhibited in the field.

Later Mr. Buehler and myself took up an investigation of the Granby area and in this locality we found that the same mistake of mapping unconformity for faulting had been made. The facts covering this area are embodied in a report on "The Geology of the Granby Area," which report was transmitted for publication in November, 1905. Before the report was distributed, Mr. Siebenthal published in ECONOMIC GEOLOGY a paper on what is known as the "Cornfield Tract" of the Joplin district, in which he shows that the evidence considered by Dr. Bain to indicate faulting was actually in the main a result of unconformity. I understand that this paper was withheld from publication by Dr. Bain until after Mr. Hayes of the U. S. Geological Survey had visited the Granby Area and verified the work which Mr. Buehler and myself had been doing in that portion of the district.

My purpose in calling attention to these facts is brought about because of the persistency with which the report upon "The Geology of the Granby Area" is ignored when any reference is made to the probable occurrence of faulting in the Joplin district. I desire, however, to give publicity to the fact that attention was first called to the errors, both as to the facts and the theory, contained in the report on "The Lead and Zinc Deposits of the Ozark Region" through the investigations of this bureau. Although it is the policy of my associates and myself to publish the results of our investigations only through the medium of the reports of this bureau, yet we feel constrained to use the pages of the contemporary journals in correcting what we believe to be erroneous statements of conditions within our immediate field of investigation.

In No. 2, Vol. II., of ECONOMIC GEOLOGY, H. Foster Bain con-

tributes an article on "Some Relations of Paleogeography to Ore Deposition in the Mississippi Valley," and also reviews the report of Professor E. Haworth on "Lead and Zinc of Kansas." These contributions by Dr. Bain are especially interesting when read together. The contribution on "Paleogeography" is significant since it is a somewhat generalized statement of conditions which have been recognized by Whitney, Chamberlin, Blake, Winslow, Spurr, myself and others. As nearly as I can interpret this paper, it is Bain's intention to confine the "parent metalliferous concentrations" of the Paleozoic formations of the Mississippi Valley exclusively to the Cambro-Ordovician. In this Bain differs from Buehler and myself—and perhaps from some of the others above mentioned—in that we believe that the lead and zinc minerals may have been originally disseminated, through chemical processes operative in the ocean, during all the various periods of sedimentation from Archean to the present time. We believe, and have so stated, that conditions have probably always existed and do exist today in some parts of the oceans or inland seas, as a result of which metalliferous minerals are being deposited with the mechanical or other chemical sediments.

The review of Haworth's report, although ostensibly not so intended, is actually a defense of the Bain-Van Hise theory of the origin of the lead and zinc ores of the Ozark region. Bain's theory of the origin of the ores of the Ozark region, which evidently he has not abandoned, requires an artesian circulation in which the water carrying lead and zinc in solution is derived, through faults, from the Cambro-Ordovician formations, 400 to 600 feet below the present surface in the so-called Joplin district.

In Bain's paper on "Paleogeography" the irregular distribution of the ore bodies is accounted for in the same manner as we have sought to account for them in our report on the Geology of the Granby Area—namely, through processes of erosion, sedimentation, and ground water circulation. On the other hand, in his review of Haworth's report on "Lead and Zinc of Kansas," he attacks the conclusion that the lead and zinc may have been derived in the main from the Pennsylvanian, giving as his

chief reason that, "so far as is known these rocks have been widely decomposed throughout the Mississippi Valley without producing a single workable deposit of either lead or zinc." In his attempt to uphold the theory promulgated in his report on "The Lead and Zinc Deposits of the Ozark Region," Bain neglects to apply the reasoning suggested in his paper on "Paleogeography" to account for the irregularity in distribution of the ore bodies. He also evidently does not appreciate the fact that a shale formation is not a likely place for openings in which the lead and zinc minerals may be concentrated, and that, on the other hand, the conditions present in a shallow sea crowded with decaying vegetation must have established exceptional conditions for the precipitation of metallic salts brought in by streams.

In referring to his theory of an artesian circulation in the Joplin district, Bain refers to Haworth's estimate that not over 10 per cent. of the water received by the mines of Kansas come from below the workings. Bain assumes that this 10 per cent. comes wholly from the Cambro-Ordovician and that it is sufficient to account for the deposition of the lead and zinc ores of the district. It will be recalled that in his report on "The Lead and Zinc Deposits of the Ozark Region," Bain says, "Except in the case of unprotected openings or very open ground, severe storms and rainy weather do not increase the amount of water that must be handled." Haworth gives abundant evidence to disprove this statement which confirms the observations of Buehler and myself in Missouri. Bain, however, takes this 10 per cent., with some doubt as to its accuracy, as sufficient to confirm his theory of an artesian circulation. Bain also refers to a quoted opinion from Mr. George Plater, a mine operator, to the effect that "one of two adjoining areas west of Joplin is not affected at all by local rainfall." Numerous observations made by this bureau, extending over several years, show that the mines as a rule pump upwards of 50 per cent. more water during rainy than during dry seasons. (See Geology of the Granby Area, Missouri Bureau of Geology and Mines, 2d Series, Volume IV., p. 21.) Attention, however, should be called to the fact that all the 10 per cent.

referred to by Haworth probably does not come from the Cambro-Ordovician, since the bottom of the mine workings are in most instances 200 or more feet above the base of the Mississippian. It is our impression that a very small part of this 10 per cent. actually comes from the Cambro-Ordovician, most of it being derived from the Mississippian underneath the bottom of the mine workings. This would be especially true where the Mississippian and Cambro-Ordovician are separated by the normal thickness of Devonian shale. The jointing connecting the mine workings with lower, porous, cherty horizons above the Cambro-Ordovician is an adequate source of the greater part of this 10 per cent.

In his paper on "Paleogeography," Bain makes mention of the southwestern Missouri District, referring to his "Preliminary Report on the Lead and Zinc Deposits of the Ozark Region" as embodying his conclusions relative to the genesis of the ores of that district. As late as September, 1904, Bain read a paper before a meeting of the American Institute of Mining Engineers in which he makes the following statements, which convey in a somewhat concise manner the conclusions reached in the report above referred to:

"The ore bodies are *everywhere* associated with the introduction of large quantities of dolomite, while the country rock is non-magnesian."

"The ore bodies are confined to particular districts and areas characterized by faulting sufficient to allow a connection to be established between the circulation of the waters in the Carboniferous limestone and that in the rocks below. *In areas where faulting is absent there is no ore.* In many cases there is a direct connection between particular faults and particular ore bodies."

"The original source of the metals is accordingly believed to have been the underlying rocks and in the main the Cambro-Ordovician dolomites."

The investigations of myself and associates have shown conclusively (1) that only a part of the ore bodies are associated with dolomite; many of them are *absolutely devoid of dolomite;*

(2) that the Carboniferous rocks contain more than sufficient magnesia to account for all the dolomite associated with the ore bodies; (3) that the faults mapped by Bain are chiefly discordances in bedding caused by unconformity. Faults of sufficient magnitude to allow a connection between the Carboniferous limestone and the rocks below have not been found; (4) that any connection between faults and ore bodies has not been established; and (5) that the conclusion that the immediate source of the metals was the Cambro-Ordovician is unwarranted since the evidence upon which that conclusion is based has not been shown to exist.

In southeastern Missouri the so-called striking differences in the composition of the ores of the Potosi and those of the Bonne Terre have led Bain to conclude that they must be referable to quite different sources or conditions of deposition. The Potosi ores he concludes have an origin analogous to that of the Wisconsin lead and zinc ores while those in the Bonne Terre he believes are epigenetic. Four years study of the ores of southeast Missouri leads me to believe that these conclusions are a little premature. Since the results of my work in this district are embodied in a report of the Bureau of Geology and Mines soon to be published, I will not take time to discuss this point.

In Bain's paper on "Paleogeography" some of the facts are evidently inadvertently omitted. Instead of the Ozark Region, which is a portion of the Mississippi Valley, being subjected to "prolonged erosion at low altitudes since Paleozoic," it is pretty well conceded that this region was submerged during both the Cretaceous and Tertiary. In southeastern Missouri, for example, we find what are supposed to be Tertiary gravels, strewn over the hillsides at an elevation of 1,000 feet above sea level. There seems to be abundant evidence to show that the Ozark portion of the Mississippi Valley was reduced to a peneplain condition and elevated at least twice in its history since the Paleozoic.

Dr. Bain says, "erosion may be regarded as a process of wet crushing or crushing in solutions. In nature it is carried on, on the grandest scale and instead of tons, cubic miles of rock are

ground up and leached. . . . It is well known that a very large number of ore-forming minerals are more or less soluble in ordinary ground water and in the construction of large land masses, immense quantities of these minerals must go into solution."

"Sedimentation proper is essentially a concentrating and a precipitating process. It is a great agency for bringing like to like. It is powerful, is present whenever land and water meet and has continued in activity through ages and eons. *It seems altogether fitting that it should be appealed to in accounting for those ore deposits in whose production tons of metal must have been concentrated from miles of rock.*"

With respect to the lead and zinc deposits of the Ozark region, we have been teaching this theory for the last five years. If a complete application of this idea were made to the Ozark region, faults and an artesian circulation would not be required to account for the ores of the Joplin and other districts in this state. However the review of Haworth's report leads us to believe that Bain has not made a broad application of this principle to the region in which, in the main, he has already applied another theory covering the genesis of the ore bodies.

E. R. Buckley.

Rolla, Mo., May 1, 1907.

HOW FAULTS SHOULD BE NAMED AND CLASSIFIED.

Sir:—Instead of using the term "shift" as a name for a special class of fracture dislocations, distinct from faults, as suggested by Professor Fairchild in the previous number of this journal, I should prefer to retain the name fault for all fracture dislocations, and to regard "shift" as merely one of the elements of fault movement. The actual separation along the fault plane of two previously adjacent particles would be the "total displacement" of the fault, and could conveniently be regarded as separable into two components, one straight up or down the fault plane (the displacement), and the other horizontal (the shift). In all except absolutely horizontal faults these directions would be fixed. It is also a convenience in many cases to regard

one of these two components, the displacement, as itself resolvable into two components in the plane perpendicular to the fault plane, a vertical component (throw) and a lateral component (heave). The total displacement is the resultant of the three components, throw, heave and shift (see Fig. 49). Any one or

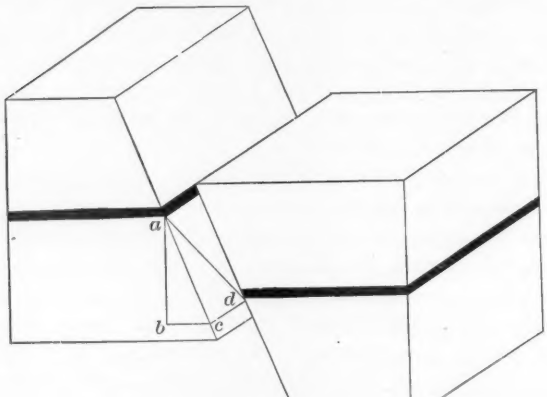

FIG. 49. Diagram showing relation of total displacement to throw, heave and shift.

any two of these may have a value of zero, in which cases the terms "throw faults," "heave faults," "shift faults" and "displacement faults" would be useful. It is exceedingly probable that the majority of faults possess an element of shift, in addition to those of throw and heave, and there would seem no valid reason for excluding a dislocation which was mainly or wholly shift from the fault class, since shifting may form any possible percentage of the total displacement.

In the case of faults in otherwise undisturbed sediments, or in massive igneous rocks, these five elements seem all that are necessary to thoroughly function the faults, but in tilted rocks they do not furnish all the data desired, even with the addition of "stratigraphic throw" (which I take to be synonymous with Spurr's "perpendicular separation"), and in such cases the addi-

tional functions named and defined by Spurr are most useful and necessary, and the throw and heave may have little practical value.

To have in use two terms so likely to be confused as displacement and total displacement is not to be recommended and it would seem better to use one or the other for the resultant of the throw, shift and heave, rather than either for the resultant of the throw and heave. Spurr uses "throw" for the latter function, to which there is the obvious objection that it was already in use for a different function, and hence confusion is introduced. It might be called the "slide" or "glide" of the fault, though neither seems a specially happy term.

Personally the attempt to supersede the old classification into normal and reversed faults by a genetic classification seems to me a trifle premature, though unquestionably necessary. But after all the precise terms that are in use are of small importance in comparison with the great desirability that we shall all use the same name for the same thing, and anything that will tend to bring about such uniformity is to be highly commended. If a discussion such as the present one will help toward this end it is to be hoped that it will be greatly prolonged.

H. P. CUSHING.

WHAT SHOULD APPEAR IN THE REPORT OF A STATE GEOLOGIST.

Sir:—In compliance with the request of the editor, I will gladly give my ideas concerning the above topic.

The subject matter in the report will necessarily depend on the character of the work done. The first consideration of a state survey, in determining the character of its work, would certainly depend upon the object of the survey as set forth in the law, by virtue of which the survey had its existence. While it may be possible, in some cases, for the state geologists to place various interpretations upon the exact meaning of the enactment creating a state survey and defining the object and the nature of its work—yet, as a whole, no misunderstanding can occur. The

real problem with the surveys, especially in the newer states, is not to determine in what field we are expected to work, but it is to decide just what sort of investigation will be most valuable in consideration of the vast amount, which might be done, with the very limited means at the disposal of the surveys. What any certain state survey should do is always dependent upon the natural resources of the state and the degree of their development in consideration of the needs of the people. But what a state survey can do is dependent upon the resources of the survey in men and money. As a rule, one might be safe in judging, that funds are appropriated with the view of the utilitarian development of the resources of the state. No one will question the appropriateness of such an aim, especially in the undeveloped states.

It should be the first duty of a survey to make an exploration of the state, in such detail as to discover the important economic products, the use of which would add to the comfort or convenience of the people. This exploration does not simply mean the discovery of valuable mineral wealth, but an investigation of the ore bodies, the coal seams, the clay beds, the cement deposits, the building stones, the oil fields, the gas belts, the artesian well areas, etc., in such a careful manner that there need not be such a waste of time and money in useless efforts to find these valuable minerals, on the one hand, nor upon the other the lack of finding them. True it is that in most states the greater part of the valuable resources have been found, yet in many much valuable work can yet be done. This additional work will be of the nature of determining, with the highest degree of accuracy, the manner of occurrence, the geological strata, the distribution, and the possible extent of the above named resources, or of any mineral products of economic value. Not only the matter of quantity, but the question of accessibility should be determined. Can the people get it without too much cost? I am acquainted with two coal beds, one is outcropping on the surface, but in an almost inaccesible place, while the other is near a city, but several hundred feet below the surface. In neither case is the coal, at

present, of any value. Location and general environment, both geological and geographical, should be studied. It is the business of a survey to not only find the useful materials, but to determine much more than their mere location. Can they be successfully utilized by the people is a question the survey must answer.

The above work will of necessity involve the making of maps and the publication of reports. These should be of such a nature as to be of the greatest possible use to the largest number. A state survey exists not for the few but for the many, hence it should benefit the masses as much as possible.

While it is true that the work of the state survey may be brought near to the people by the discovery of new and valuable industries, or by suggestions and explorations showing how unprofitable ones may be made to pay, and by charts, maps and reports, giving formations condition and statistics, yet there is a second great aim of the state survey which must not be omitted—the educational phase of the work should be remembered as well as the utilitarian side. The survey publications should be of especial value to the schools of the state. If the educational side of the survey's work is not of the most important it certainly is of great value, or should be so considered.

A large amount of excellent work in such sciences as geology, botany, zoology and physical geography, can, and should, be done in our schools from data furnished by the survey. This will have a two fold benefit, it will give the pupils and students a better knowledge and hence a higher appreciation of their own state; and it will also give to the people generally a better idea of the real worth of the work done by the survey. There is another way in which the work of the survey can add to its educational influence. Both teachers and pupils, as well as all intelligent citizens, will be interested in seeing a large and valuable collection of type fauna and flora of the state put into a museum, where the animals are all properly mounted, labelled and described; and the plants including wild-flowers and grasses are put into a systematic collection properly classified and named.

Such a collection of wild animals and native plants would be of exceptional value, certainly well worthy of the best efforts of the survey.

Hence I should let the Report of the State Geologist include not only the discovery and general exploitation of the economic resources of the state, but let it be of such a character that the masses of the people, through their schools, will derive much that is of an educational value.

ELLWOOD C. PERISHO.

THE UNIVERSITY OF S. D.,
DEPT. OF GEOLOGY.

REVIEWS

The Geological Plans of Some Australian Mining Fields. By J. W. GREGORY, F.R.S., Professor of Geology, University of Glasgow. "Science Progress," No. 1, July, 1906.

In this brief paper of twenty pages the author has given a short description of six mining districts of Australia, and although no attempt has been made to present in any way an exhaustive discussion of the several very important districts mentioned, some very vital points are treated which will go far to correct certain geological misconceptions that have crept into the literature of ore deposits.

The author first treats of the Mount Lyell copper field, showing that the ore there occurring is deposited in two separate ways: (1) as fahlbands in the mineralized schists which are commercially the less important of the two and two large ore masses of pyrite containing quartz, barite, chalcopyrite and some gold and silver and in one instance having a surface dimension of eight hundred feet along the strike and two hundred feet in width. The distribution of the ore is intimately associated with the geology of the district.

The eastern portion of the district consists of Palæozoic sediments with mesozoic diabase underlain by metamorphic schists of undetermined age. The schists cover the northern and eastern portion of the area but in the west the palæozoic sediments, especially the basal conglomerates have been dropped by a N. and S. fault against the schists on the west.

A series of later nearly east and west faults have intersected this fault and the result has been the occurrence of masses of schist within the area of the conglomerate and palæozoic sediments.

On one of the schist masses now nearly enclosed by conglom-

erates brought into juxtaposition by the faults is the Mount Lyell mine.

The Mt. Bischoff tin mine is then described. It is in an elevated area of folded Silurian rocks pierced by quartz porphyry dikes. The nature of the mine will best be understood by quoting the author's own language.

"The tin ores are of three main types: (1) A quartz vein charged with tin forms the Queen lode, on the northeastern side of the mine; this lode follows along a porphyry dyke, which it overlies near the outcrop; when it was followed downward, it was found to cut across the dyke and then continue beside, but underneath it. (2) Cassiterite also occurs in masses and veins in contact with the porphyry dykes, in pockets and veins in the Silurian slates, and as impregnations in the porphyry. (3) The main wealth of the mine comes from a large mass of iron-stained material, known as the Brown Face, which includes some coarse bedded sand, yielding up to 10 and even 15 per cent. of cassiterite. This Brown Face is bounded to the east by a sloping face of the Silurian slates, the junction being a strong fault plane. To the west it is bounded by altered Silurian rocks, separated from unaltered contorted slates by the western arm of the quartz porphyry dyke.

"The special problem in the geology of the Mount Bischoff Mine is in the nature of the Brown Face. Its coarsely bedded, loose material at first inevitably suggests that this brown, iron-stained mass is a sedimentary deposit, filling up a crater-shaped basin within the dykes. But this simple hypothesis unfortunately does not seem adequately to explain the facts. Part of the gossan is certainly porphyry in the last stage of decomposition. The grains in the tin-bearing sands are angular, and do not appear water-worn, and they may be derived from rocks containing quartz grains, which have broken down into rotten-stone by the removal of the cement simultaneously with the introduction of the tin. The whole Brown Face seems to me to be a gossan. It was probably formed by the oxidation of a mineralized mass of quartzites and slates, with some intrusive porphyry

dykes; most of this mass had been impregnated with pyrites and the rest of it with cassiterite. The pyrites have been converted into limonite, the bases removed (probably as soluble sulphates), and the settling of the decaying rock mass has in places produced a false bedding. The intensity of the chemical changes that have taken place in the rocks of this mine is shown by the alteration of some of the porphyry into radial clusters of topaz, and the partial alteration of the rock into a topaz greissen."

The significant point in connection with this mine is the conspicuous absence of granite. It has become so customary in general treatises on ore deposits to consider tin as inevitably associated with intrusions of granite that the knowledge that there is no necessary genetic connection is of great importance.

The reviewer has recently learned from Mr. J. E. Spurr[1] that similar occurrences are found in certain Mexican districts—veins of cassiterite and topaz intimately associated with rhyolite intrusives. It would therefore seem that ores of tin which are perhaps the most indisputable of all the so-called pneumatolytic deposits may be formed by emanations from porphyritic as well as deep-seated intrusions, a condition which does much to support the magmatic theory of ore-deposition.

The author then takes up the Australian saddle reefs and shows that they have been supposed to occur at (*a*) Bendigo; (*b*) Castlemaine, and (*c*) Broken Hill.

The Bendigo district needs no further mention here but the conditions at Castlemaine are shown to be quite distinct as it is here that the alluvial deposits derived from the reefs are rich and the reefs themselves, poor, the reverse conditions obtaining in Bendigo.

It is then shown that the so-called saddle reef of Broken Hill is in the lamination of a metamorphic igneous rock and not in the more regular anticlinal folds of a series of contorted sediments. The inference is drawn that there is no necessary superposition of saddle reefs at Broken Hill as the lamina of metamorphic rocks or foliated igneous rocks cannot be relied upon to

[1] Oral communication.

produce superposed anticlines and the occurrence of one saddle above by no means indicates the presence of others below.

The latter part of the paper contains a brief discussion of the indicators of Ballarat and corrects an erroneous impression which has found its way into the literature of the subject. It is of sufficient importance to warrant a quotation in full.

"The early miners of Ballarat were faced by the paradox of finding gold in large nuggets and coarse grains in the gravels, and yet the adjacent hills, though the rocks were exceptionally well shown, contained no quartz veins comparable in size to the nuggets shed from them. Hence arose the belief that the nuggets grew by slow accretion in the gravels from percolating gold solutions. This theory has been now almost universally abandoned; but it is of historic interest as indicating the difficulty of believing, that the nuggets could have been derived from the small, irregular quartz veins, that seam the hills of Ballarat East.

"The nuggets found in the surface gravels and soils of Ballarat have been found along a line running north and south through the town and suburbs of Ballarat East. The nuggets were no doubt formed in small quartz veins, where they are cut across by narrow seams called indicators. These indicators have been generally regarded as originally layers of sediment especially rich in organic matter. Each indicator was thought to have been deposited as one bed in the succession of clays and sandstones laid down on the floor of a Lower Palæozoic sea. The decomposition of the organic matter was considered to have formed iron pyrites in these particular bands of clay. Later on the rocks have been tilted, until they are nearly or quite vertical, and at the same time the clays have been cleaved into slates and the sandstones altered to quartzites. Solutions percolating through horizontal cracks in these rocks deposited vein quartz; and it was thought that the gold in the solutions precipitated patches or nuggets opposite the seams of iron pyrites.

"This theory has been so widely expressed in mining literature that it was a great surprise to me to find, on surveying the Bal-

larat East mines for the Victorian Mines Department, that it cannot be confirmed. The indicators are not interstratified beds; but as had been maintained by Mr. William Bradford, of Ballarat, they cross the bedding planes irregularly. They are secondary in origin, and, though they are limited to particular bands of slates, they do not occupy uniform positions in these bands.

"Microscopic examination of the indicators, moreover, show that they are not layers of pyrites. This view was based on the fact that they appear, in the upper levels of the mines, as thin, iron-stained bands; and the iron was thought to be derived from decomposed pyrites. The typical indicators are seams of chlorite; one of them, the Pencil Mark, is a thin band, rendered black by the abundance of fine needles of rutile.

"The indicators are seams of secondary minerals, generally chlorites, developed along slip-bands traversing the slates."

J. D. IRVING.

SCIENTIFIC NOTES AND NEWS[1]

THE AMERICAN CERAMIC SOCIETY at its last meeting decided to appoint a Committee of five to consider the lines of work which it was desirable for the Federal and State Surveys to pursue in studying the clay deposits of the United States and testing clay products. The Committee appointed consists of R. R. Hice of Beaver, Pa., chairman; R. C. Purdy, Urbana, Ill., Secretary; H. Ries, Ithaca, N. Y.; H. A. Wheeler, St. Louis, Mo.; and A. V. Bleininger, Columbus, Ohio.

The Committee met in Columbus, Ohio, on March 22d and 23d and drew out a set of recommendations for transmittal to the United States Geological Survey and the State Geological Surveys.

THE STATE GEOLOGICAL SURVEY OF MARYLAND has recently installed an extensive collection of the state's mineral products at the State House at Annapolis, the old Hall of the House of Representatives having been placed at its disposal. Much of the material had been earlier collected for the exhibits made at Buffalo, Charleston, and St. Louis.

DURING MARCH PROFESSOR T. C. CHAMBERLIN, of the University of Chicago, delivered three lectures on geological subjects at the University of Wisconsin.

THE MARYLAND GEOLOGICAL SURVEY is preparing in cooperation with the U. S. Geological Survey a series of folios which will be published by the latter organization on the scale of one mile to the inch, extending from the Alleghany plateau to the Chesapeake Bay.

The object of these folios is largely educational since they

[1] Geologists, mining engineers and others interested in applied geology are invited to keep the editor informed of new investigations of mining districts or scientific studies undertaken by them, together with such other scientific and personal items as may come to their notice.

present the sequence of geological formations of the middle Atlantic border from the Archean to the Pleistocene and will offer to students the most recent interpretation of the geology of this belt.

GEOLOGICAL STUDENTS at the University of Wisconsin took a ten days trip to the Lake Superior region, leaving May 4th, in charge of Professor C. K. Leith.

PLANS HAVE RECENTLY BEEN PERFECTED for a detailed and systematic investigation of the Atlantic and Gulf Coastal Plain stratigraphy and paleontology, several State Surveys, including North Carolina, Georgia, Alabama, and Mississippi acting in cooperation with the United States Geological Survey in the studies. The aim of the work is to determine the extent of the subdivisions recognized in New Jersey and Maryland on the north and Alabama on the south, to determine their relations to one another, and in general to establish satisfactory correlations throughout the district between the Potomac and the Mississippi River. Considerable economic studies, especially on the phosphates, will also be made incidentally. The general supervision of the work rests with a board of supervising geologists, consisting of the State Geologists in the Coastal Plain districts and the Chief Geologist and Chief Hydrographer of the National Survey, Dr. W. B. Clark being Chairman. The field work is in charge of Mr. M. L. Fuller, who will put seven parties into the field the coming summer. It is hoped to complete the investigation in Virginia, North Carolina, South Carolina, and Florida during the next year, while the work in the remaining States will be finished in 1908 and 1909.

A MONOGRAPH ON THE PLIOCENE and Pleistocene formations of Maryland has just been issued by the State Geological Survey. The geological chapters have been prepared by G. B. Shattuck and the paleontological chapters by Messrs. Wm. Bullock Clark, F. A. Lucas, Arthur Hollick, E. O. Ulrich, O. P. Hay, and E. H. Sellards.

DR. ALEXANDER N. WINCHELL, of the Montana State School of Mines, has been elected to fill the chair of Petrography and

Mineralogy, formerly held by Professor William H. Hobbs, at the University of Wisconsin.

THE MARYLAND GEOLOGICAL SURVEY has in preparation and nearly completed a monograph on the Devonian formations of the State, the authors being Charles Schuchert, J. M. Clarke, Charles S. Prosser, and Charles K. Swartz. The faunas of the several formations have been fully described and illustrated as in the case of the other volumes of the Survey.

THE MARYLAND GEOLOGICAL SURVEY has charge under recent acts of the State Highway system and has had under construction a large number of State highways in different sections of the State. It is employed at the present time in building a boulevard between Baltimore and Washington under a special act passed by the last Legislature and it is planned to continue this road later to the north of Baltimore along the line of the Philadelphia road, making a through north and south highway across the state. A similar east and west highway has also been planned.

WITHIN THE LAST FEW WEEKS a bill has passed the Canadian House of Parliament establishing a Department of Mines in the Dominion of Canada. For many years past there has been an Inspector of Mines in the Department of the Interior, whose work has been unconnected with that of the Geological Survey of Canada. The new Department of Mines will embrace all the work in any way connected with mining carried on by the Federal Government of Canada, including both that formerly carried on under the Department of the Interior as well as various activities of the Geological Survey. This new Department will be administered by a Deputy Minister of Mines, who is directly responsible to the Minister of Mines, who has a seat in the Cabinet. Mr. A. P. Low, heretofore the Director of the Geological Survey of Canada, has been appointed to this important position. The Department of Mines has two Branches, namely the Mines Branch and the Geological Survey Branch. Each of these has at its head a Director. The Mines Branch has assigned to it the work of the Department which is most closely and intimately connected with the actual operation of

mining, as, for instance, the geological surveying of mining camps, the issue of special bulletins dealing with economic resources of the Dominion, experimental work in connection with the utilization of ores and fuels, etc. It also has charge of the compilation and issue of the mineral statistics of the Dominion. To the Geological Survey Branch belongs all the general areal mapping of Canada and the conduct of geological surveys with the exception of those dealing with actual mining areas; also all geological exploration. The Geological Survey Branch also has charge of investigations in connection with the natural history and paleontology of the Dominion and will now undertake the work in connection with forestry and hydrography, thus considerably enlarging its former scope. Dr. Eugene Haanel, whose name is well known in connection with his recent investigations on electric smelting, etc., has been appointed Director of the Mines Branch under Mr. Low. For the present no appointment will be made to fill the position of Director of the Geological Survey Branch, the Deputy Minister of the Department of Mines for the present undertaking the duties of that position. The Mining interests of the Dominion of Canada have grown so enormously within the last few years as to fully warrant the Government in granting increased appropriations such as will be required for the staff and equipment of the new Department. The Department of Mines will probably be housed in the great Victoria Museum which is now being built at Ottawa and which when completed will afford excellent accommodation for the collections as well as office and laboratory room for the staff of the Department.

DURING THE PRESENT SUMMER the following investigations will be carried on in the Mines Branch of the Department of Mines, Canada: Mr. Fritz Cirkel will study the chrome iron-ore deposits of the eastern townships of Quebec. Mr. J. W. Bell will collect material in Nova Scotia, New Brunswick and Quebec, and Mr. Robert Hedley in British Columbia, Alberta, Saskatchewan and Manitoba, for a report on the mining and metallurgical industries of Canada. Mr. E. Lindeman will investigate the

iron ore resources of Vancouver Island and ascertain the conditions necessary for the inauguration of an iron industry in British Columbia. Mr. E. Nystrom will investigate the peat industry in Europe and Mr. B. F. Haanel will study the occurrence of iron ore in the township of Leeds, Quebec.

In the Geological Survey Branch, Messrs. McConnell and Maclaren will make an examination of the mineral deposits of the southern part of the Yukon Territory, including the copper deposits of Whitehorse and the rich silver deposits of Conrad, while Mr. Cairnes will map and study the coal areas along the Yukon between Whitehorse and Tantalus. In British Columbia Mr. J. A. Bancroft will continue the examination of the rocks and minerals northward from Texada Island, giving particular attention to the copper and iron deposits; Mr. Leach will study the coal and copper areas in the vicinity of Buckley Valley, Skeena River; and Messrs. Brock and Boyd will complete the investigation of the Rossland camp. In Alberta, Mr. Malloch will continue the mapping of the Cascade, Palliser and Costigan coal fields in the Rocky Mountains. In Quebec, Mr. Dresser will study the serpentines of the eastern townships with special reference to the mode of occurrence of chrome iron ore, copper ore and asbestos. In Nova Scotia, Messrs. Faribault and O'Farrell will continue the study of the gold-bearing rocks in Lunenburg and Queens counties and Dr. Young will investigate the granites and other igneous rocks with special reference to the occurrence of tin and other valuable materials.

MR. W. H. EMMONS of the United States Geological Survey gave a six weeks course of lectures on ore deposits at the University of Chicago in May and June. The course was to have been given by Mr. F. L. Ransome who was prevented by illness from fulfilling his engagement.

BEGINNING WITH JUNE, 1907, the economic work of the U. S. Geological Survey so far as regards the metalliferous deposits will be in charge of Mr. Waldemar Lindgren who will exercise both scientific supervision and administrative control over this branch of the service.

THE CANADIAN MINING JOURNAL, the first number of which recently appeared, has incorporated with it the CANADIAN MINING REVIEW which for twenty-three years has been the leading mining journal of Canada. The editorial staff is composed of able men whose reputations are an earnest of a successful future for the new journal.

A CONFERENCE OF STATE GEOLOGISTS was held in Washington May 20–21 to discuss coordination of the work of the Federal and State Surveys.

MR. H. A. BUEHLER, Assistant State Geologist of Missouri, has resigned to engage in professional work. His resignation will take effect July 1, 1907. Mr. Buehler's successor has not been selected.

THE XCIIID MEETING of the American Institute of Mining Engineers will be held at Toronto, Canada, beginning on Tuesday afternoon, July 23, 1907. Mr. W. G. Miller, Provincial Geologist, Bureau of Mines, Toronto, may be addressed as the representative of the Local Committee in charge of the programme and excursions. Communications concerning papers and discussions should be sent to Dr. R. W. Raymond, Secretary, United Engineering Society Building, 29 West 39th St. New York.

THE DIRECTOR of the Geological Survey of New Zealand, Mr. J. M. Bell, reports that several economic bulletins are in preparation, notably on the Hauraki gold district near Auckland and on the great Parapara iron deposit in Nelson Province. During the year some valuable discoveries of copper ore have been made, chiefly in a very rugged country south of the Karamea River in Nelson Province. The ores occur in quartzose veins in granite and consist of chalcopyrite with a little bornite and some molybdenite.

MR. H. D. MCCASKEY, formerly chief of the Philippine Mining Bureau, has joined the staff of economic geologists of the U. S. Geological Survey, and is now in Washington.

THE DIVISION OF ALASKAN MINERAL RESOURCES of the U. S. Geological Survey will continue geologic, topographic, and

hydrographic work in Alaska during the season of 1907. Five geologic, three topographic, and two hydrographic parties will visit widely separated districts. The copper deposits in the valley of Chitina River, a tributary to Copper River, will be examined by F. H. Moffit, assisted by A. G. Maddren. The importance of this field has been demonstrated by prospecting and material for steamboats to be used on Copper River was taken in via Valdez over the snow this spring. The steamers will aid in the construction of the Copper River railroad. L. M. Prindle will make stratigraphic studies in the Forty-mile and Rampart districts of the Yukon region, and P. S. Smith with two assistants study the areal geology and mineral resources of the Solomon and Casadepaga quadrangles in Seward Peninsula. Special interest is attached to this field because gold placers are worked by a mammoth steam dredge and the only quartz lode mine in western Alaska is located here. Adolph Knopf has gone to Cape York region and other localities on Seward Peninsula to investigate tin deposits, and W. W. Atwood is visiting the coal fields in southeast Alaska and along the Yukon. C. W. Wright and Sidney Paige are studying the ore deposits of Kasaan Peninsula.

A REPORT WHICH SHOULD BE of interest to mining geologists, and particularly to those who are interested in the theory of ore deposition, has been published recently by the United States Geological Survey as Professional Paper No. 57, on the Marysville mining district, Montana, by Joseph Barrell of Yale University. The economic importance of the district has been on the wane for a number of years but the worked-out mines offered an opportunity to study the relations and origin of the gold-bearing quartz veins on the margin of a small batholith.

PLANS FOR THE SUMMER WORK of the State Geological Survey of Illinois include a continuation of the coöperative coal surveys under the direction of Assistant State Geologist DeWolf, assisted by Messrs. J. A. Udden, J. R. Browan and A. J. Ellis; a systematic survey of the portland cement materials under the general direction of U. S. Grant, with J. A. Udden, A. J. Ellis, Stuart

Weller and T. E. Savage assisting; a further study of the clays by E. F. Lewis and a re-study of the oil fields by H. F. Bain. Mr. Stuart Weller will be principally concerned with the Mississippian limestones and their stratigraphy. Mr. Savage will study the Devonian. Professor Salisbury, assisted by Messrs. Trowbridge and Jones, will study the Wheaton and Springfield quadrangles with a view to the preparation of an educational bulletin.